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Environmental Fatigue Analysis
for the
Vermont Yankee
Reactor Pressure Vessel
Feedwater Nozzles

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1.0 INTRODUCTION

In Table 4.3-3 of the Vermont Yankee (VY) License Renewal Application (LRA), the 60-year cumulative usage factor (CUF) value for the reactor pressure vessel (RPV) feedwater nozzle (FW) is reported as 0.750. Application of an environmentally assisted fatigue (EAF) multiplier, as required for the license renewal period, resulted in an unacceptable EAF CUF value of 2.86. Therefore, further refined analysis was necessitated to show acceptable EAF CUF results for this component.

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The VY FW nozzles were re-evaluated in detail by SI in 2004 for EPU and 60 years of operation. However, that analysis used conservative transient definitions and cyclic projections for 60 years of operation that have since been updated as a part of LRA development.

This report documents a refined fatigue evaluation for the VY FW nozzle. The intent of this evaluation is to use refined transient definitions and the revised cyclic transient counts for 60 years for a computation of CUF, including EAF effects, that is more refined than previously performed fatigue analyses. The fatigue-limiting locations in the FW nozzle and safe end are included in the evaluation, to be consistent with NUREG/CR-6260 [16] needs for EAF evaluation for license renewal. The resulting fatigue results will be used as a replacement to the values previously reported in the VY LRA.

The refined evaluation summarized in this report included development of a detailed finite element model of the FW nozzle, including relevant portions of the safe end, thermal sleeve, and the RPV wall. Thermal and pressure stress histories were developed for relevant transients affecting the FW nozzle, including any effects of EPU, as specified by the VY RPV Design Specification [3], the VY EPU Design Specification [17] and other boiling water reactor (BWR) operating experience. The thermal and pressure stress histories were used to determine total stress and primary plus secondary stress for use in a subsequent fatigue evaluation. Stresses were also included due to loads from the attached piping for application in the stress/fatigue analysis based on the bounding reaction loads obtained from the relevant design documents. The revised fatigue calculation was performed using Section III methodology from the 1998 Edition, 2000 Addenda of the ASME Code [15], and was performed using actual cycles from past plant operation projected out to 60 years of operation.

1.1 Green's Function Methodology

In order to provide an overall approach and strategy for evaluating the feedwater nozzle, the Green's Function methodology and associated ASME Code stress and fatigue analyses are described in this section.

Revised stress and fatigue analyses are being performed for the feedwater nozzle using ASME Code, Section III methodology. These analyses are being performed to address license renewal requirements to evaluate environmental fatigue for this component in response to Generic Aging Lessons Learned (GALL) Report [22] requirements. The revised analysis is being performed to refine the fatigue usage so that an environmental fatigue factor can be determined for subsequent license renewal efforts.

Two sets of rules are available under ASME Code, Section III, Class 1 [15]. Subparagraph NB-3600 of Section III provides simplified rules for analysis of piping components, and NB-3200 allows for more detailed analysis of vessel components. The NB-3600 piping equations combine by absolute sum the stresses due to pressure, moments and through wall thermal gradient effects, regardless of where within the pipe cross-section the maximum value of the components of stress are located. By considering stress signs, affected surface (inside or outside) and azimuthal position, the stress ranges can be significantly reduced. In addition, NB-3600 assigns stress indices by which the stresses are multiplied to conservatively incorporate the effects of geometric discontinuities. In NB-3200, these are not required, as the stresses are calculated by finite element analysis and any applicable stress concentration factors. This generally results in a net reduction of the stress ranges and consequently, in the fatigue usage. Article 4 [27] methodology was originally used to evaluate the feedwater nozzle. NB-3200 methodology, which is the modern day equivalent to Article 4, is used in this analysis to be consistent with the Section III design bases for this component, as well as to allow a more detailed analysis of this component. In addition, several of the conservatisms originally used in the original feedwater nozzle evaluation (such as grouping of transients) are removed in the current evaluation so as to achieve as accurate a CUF as reasonably achievable.

For the feedwater nozzle evaluated as a part of this work, stress histories will be computed by a time integration of the product of a pre-determined Green's Function and the transient data. This Green's Function integration scheme is similar in concept to the well-known Duhamel theory used in structural dynamics. A detailed derivation of this approach and examples of its application to specific plant locations is contained in Reference [4]. A general outline is provided in this section.

The steps involved in the evaluation are as follows:

- Develop finite element model
- Develop heat transfer coefficients and boundary conditions for the finite element model
- Develop Green's Functions
- Develop thermal transient definitions
- Perform stress analysis to determine stresses for all thermal transients
- Perform fatigue analysis

A Green's Function is derived by using finite-element methods to determine the transient stress response of the component to a step change in loading (usually a thermal shock). The critical location in the component is identified based on the maximum stress, and the thermal stress response over time is extracted for this location. This response to the input thermal step is the "Green's Function." Figure 1-1 shows a typical set of two Green's Functions, each for a different set of heat transfer coefficients (representing different flow rate conditions).

To compute the thermal stress response for an arbitrary transient, the loading parameter (usually local fluid temperature) is deconstructed into a series of step-loadings. By using the Green's Function, the response to each step can be quickly determined. By the principle of superposition, these can be added (algebraically) to determine the response to the original load history. The result is demonstrated in Figure 1-2. The input transient temperature history contains five step-changes of varying size, as shown in the upper plot in Figure 1-2. These five step changes produce the five successive stress responses in the second plot shown in Figure 1-2. By adding all five response curves, the real-time stress response for the input thermal transient is computed.

The Green's Function methodology produces identical results compared to running the input transient through the finite element model. The advantage of using Green's Functions is that many individual transients can be run with a significant reduction of effort compared to running all transients through the finite element model. The trade-off in this process is that the Green's Functions are based on constant material properties and heat transfer coefficients. Therefore, these parameters are chosen to bound all transients that constitute the majority of fatigue usage, i.e., the heat transfer coefficients at 300°F bound the cold water injection transient. In addition, the instantaneous value for the coefficient of thermal expansion is used instead of the mean value for the coefficient of thermal expansion. This conservatism is more than offset by the benefit of not having to analyze every transient, which was done in the VY reactor feedwater nozzle evaluation.

Once the stress history is obtained for all transients using the Green's Function approach, the remainder of the fatigue analysis is carried out using traditional methodologies in accordance with ASME Code, Section III requirements.

Fatigue calculations are performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology. Fatigue analysis is performed for the three limiting locations (two in the safe end and one in the nozzle forging, representing the three materials of the nozzle assembly) using the Green's Functions developed for the three feedwater flow conditions and 60-year projected cycle counts.

Three Structural Integrity utility computer programs are used to facilitate the fatigue analysis process: STRESS.EXE, P V.EXE, and FATIGUE.EXE. The first program, STRESS.EXE, calculates a stress history in response to a thermal transient using a Green's Function. The second program, P-V.EXE, reduces the stress history to peaks and valleys, as required by ASME Code fatigue evaluation methods. The third program, FATIGUE.EXE, calculates fatigue from the reduced peak and valley history using ASME Code, Section III range-pair methodology. All three programs are explained in detail and have been independently verified for generic use in the Reference [14] calculation.

In order to perform the fatigue analysis, Green's Functions are developed using the finite element model. Then, input files with the necessary data are prepared and the three utility computer programs are run. The first program (STRESS.EXE) requires the following three input files:

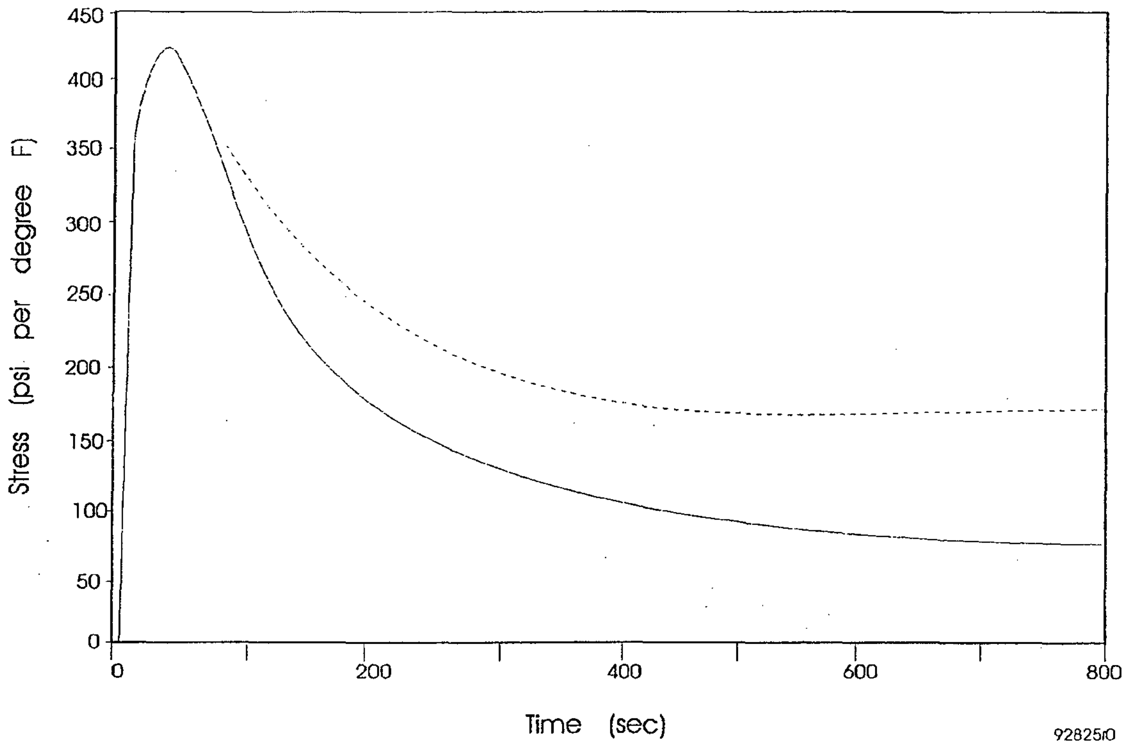
- Input file "GREEN.DAT": This file contains the Green's Function for the location being evaluated. For each flow condition, two Green's Functions are determined: a membrane plus bending stress intensity Green's Function and a total stress intensity Green's Function. This allows computation of total stress, as well as membrane plus bending stress, which is necessary to compute K_e per ASME Code, Section III requirements.

- Input file "GREEN.CFG": This file is a configuration file containing parameters that define the Green's Function (i.e., number of points, temperature drop analyzed, etc.).
- Input file "TRANSNT.INP": This file contains the input transient history for all thermal transients to be analyzed for the location being evaluated.

Pressure and piping stress intensities are also included for each transient case, based on pressure stress results from finite element analysis and attached piping load calculations.
The second program (P-V.EXE) simply extracts only the maxima and minima stress (i.e., the peaks and valleys) from the stress histories generated by program STRESS.EXE.

The third program (FATIGUE.EXE) performs the ASME Code peak event-pairing required to calculate a fatigue usage value. The input data consists of the output peak and valley history from program P-V.EXE and a configuration input file that provides ASME Code configuration data relevant to the fatigue analysis (i.e., K_e parameters, S_m, Young's modulus, etc.). The output is the final fatigue calculation for the location being evaluated.

The Green's Function methodology described above uses standard industry stress and fatigue analysis practices, and is the same as the methodology used in typical stress reports. Special approval for the use of this methodology is therefore not required.



Note: A typical set of two Green's Functions is shown, each for a different set of heat transfer coefficients (representing different flow rate conditions).

Figure 1-1. Typical Green's Functions for Thermal Transient Stress

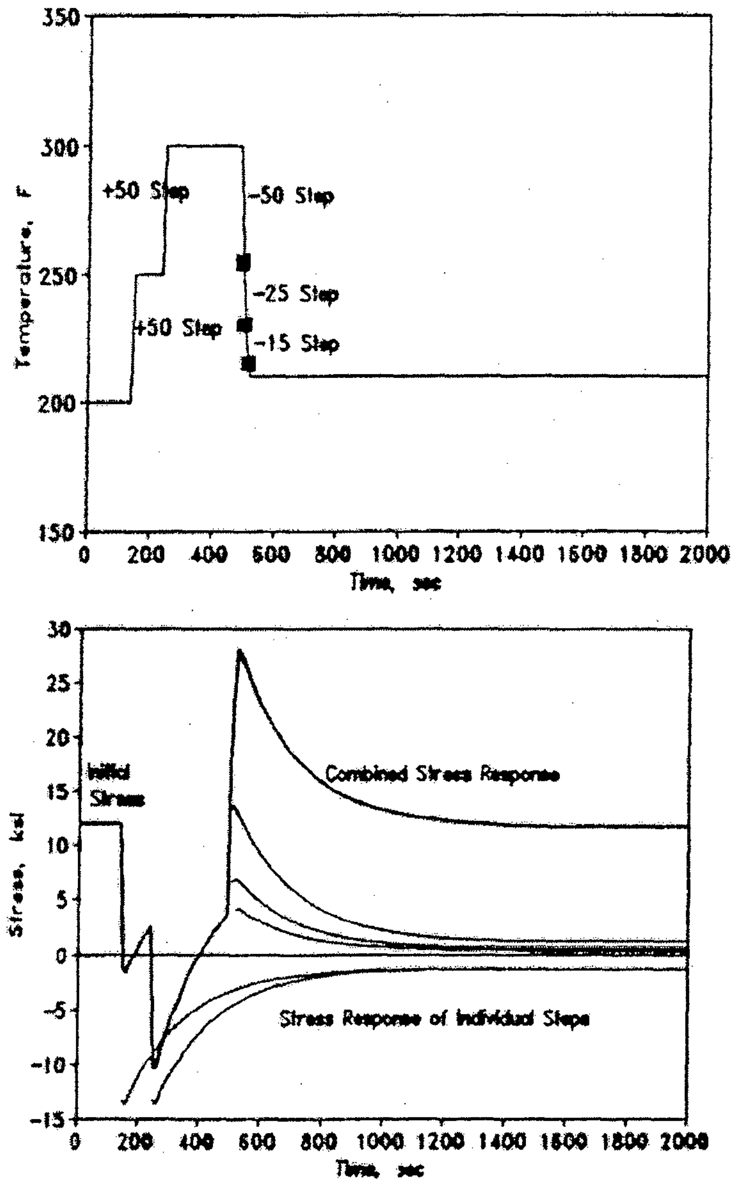


Figure 1-2. Typical Stress Response Using Green's Functions

2.0 FINITE ELEMENT MODEL

A previously generated ANSYS [5] finite element model (FEM) of the VY feedwater nozzle and safe end was used to perform the updated stress and fatigue analyses. The details of the model development are documented in the Reference [6] calculation.

A few key points with respect to model development are as follows:

- The model is identical to the geometry and mesh of the model previously developed for feedwater nozzle fracture mechanics work performed for VY [7].
- The boundary condition corresponding to the location of the start of the thermal sleeve in the FEM are consistent with Reference [8].

The materials of the various components of the model are listed below:

- Reactor Pressure Vessel – SA533 Grade B
- Reactor Pressure Vessel Cladding – Stainless Steel
- Nozzle Forging – ASTM A508 Class II
- Safe End Forging – ASTM A508 Class I
- Feedwater Piping – ASTM A106 Grade B

The FEM model the radius of RPV was increased by a factor of two to account for the fact that the vessel portion of the finite element model is a sphere and the actual geometry is a cylinder.

Material properties were based upon the 1998 ASME Code, Section II, Part D, with 2000 Addenda [9], and are shown in Table 2-1. The properties were evaluated at an average temperature of 300°F. This average temperature is based on a thermal shock of 500°F to 100°F which was applied to the FEM model for Green's Function development.

The finite element model is shown in Figures 2-1 and 2-2.

Table 2-1. Material Properties @ 300°F (1)

Material Ident.	Young's Modulus, E x 10^6 (psi)	Instantaneous Coefficient of Thermal Expansion, α x 10^{-6} (in/in-°F)	Density, ρ (lb/in^3) (assumed)	Conductivity, k (BTU/hr-ft-°F)	Diffusivity, d (ft^2/hr)	Specific Heat, c_p (BTU/lbm-°F) (see Note 5)	Poisson's Ratio (assumed)
SA533 Grade B, A508 Class II (see Note 2)	26.7	7.3	0.283	23.4	0.401	0.119	0.3
SS Clad (see Note 3)	27.0	9.8	0.283	9.8	0.160	0.125	0.3
A508 Class I (see Note 4)	28.1	7.3	0.283	32.3	0.561	0.118	0.3
A106 Grade B (see Note 4)	28.3	7.3	0.283	32.3	0.561	0.118	0.3

Notes
1. The material properties applied in the analyses are taken from ASME Section II Part D 1998 Edition with 2000 Addenda. This is consistent with information provided in the Design Input Record (page 13 of VY EC No. 1773, SI File No. VY-16Q-209). The use of a later code edition than that used for the original design code is acceptable since later editions typically reflect more accurate material properties than was published in prior Code editions. Material Properties are evaluated at 300°F from the 1998 ASME Code, 2000 Addenda, Section II, Part D [9], except for density and Poisson's ratio, which are assumed typical values.
2. Properties of A508 Class II are used (3/4Ni-1/2Mo-1/3Cr-V).
3. Properties of 18Cr - 8Ni austenitic stainless steel are used.
4. Composition = C-Si.
5. Calculated as $k/(\rho d)/12^3$.

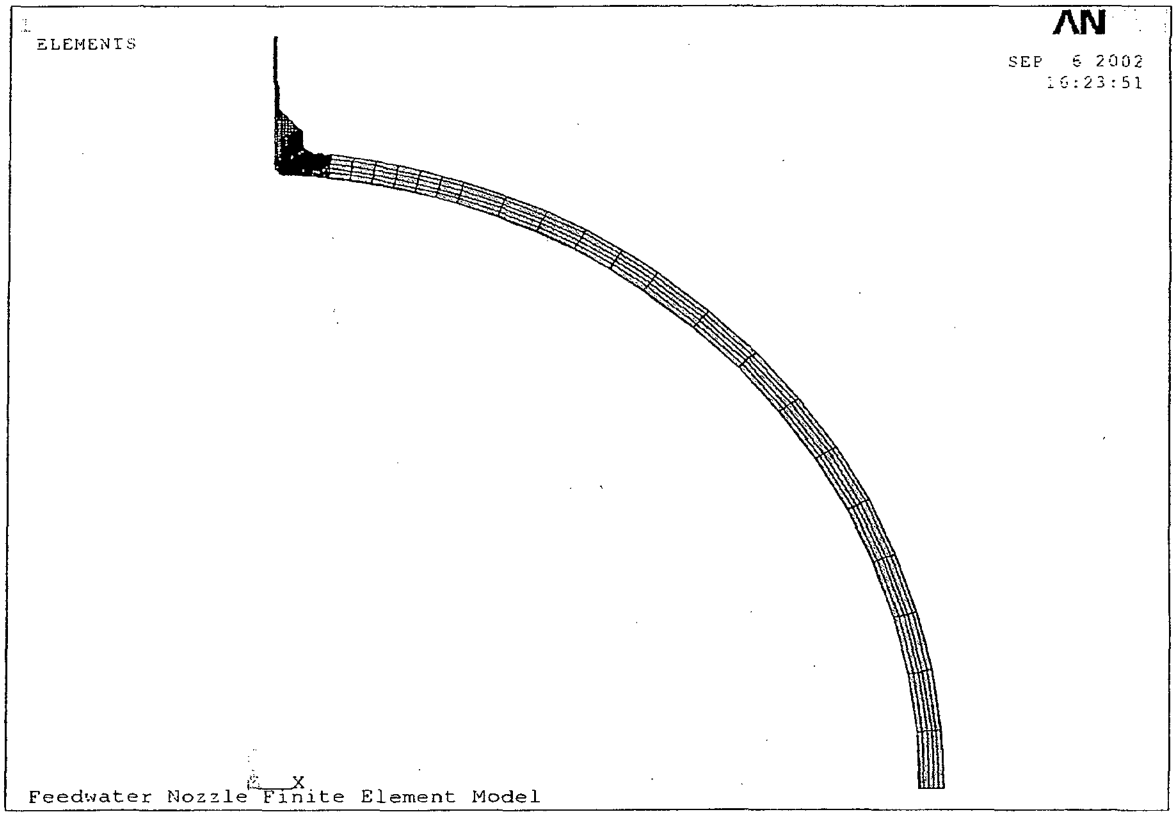


Figure 2-1: VY Feedwater Nozzle FEM

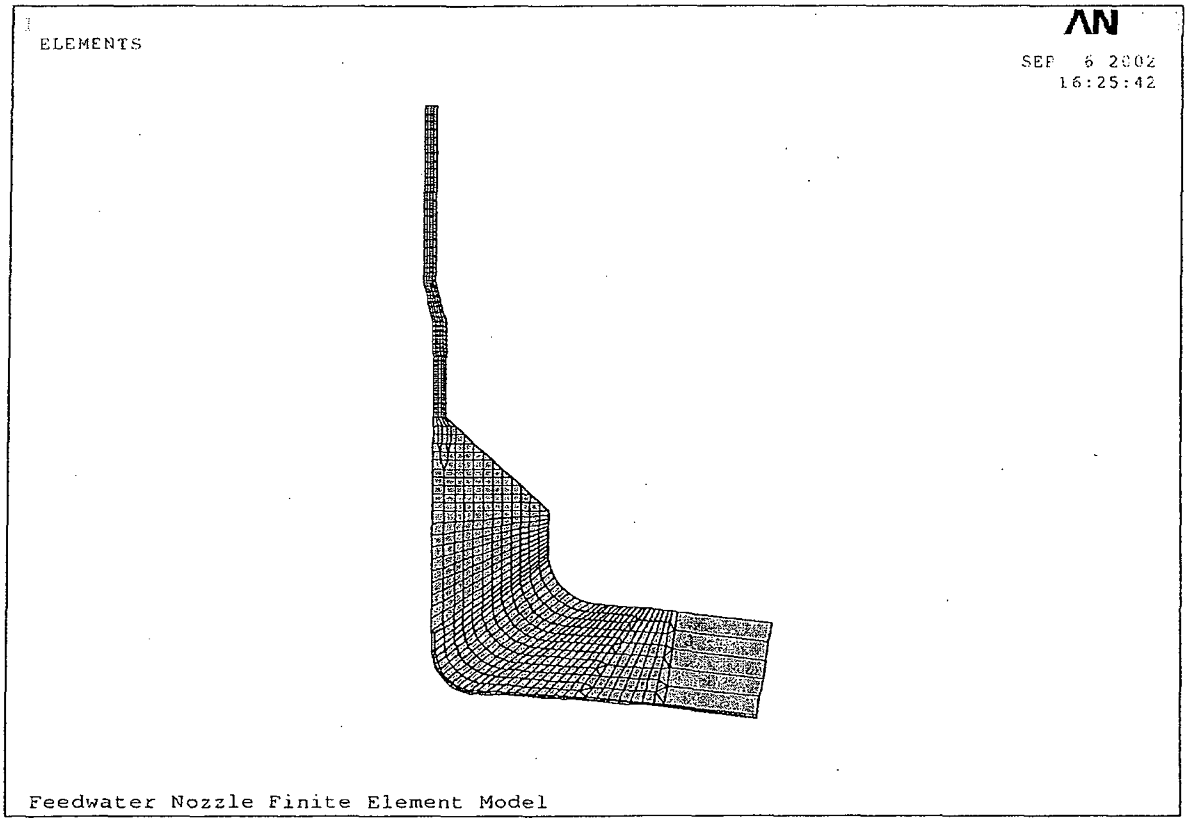


Figure 2-2: VY Feedwater Nozzle FEM – Safe End/Nozzle Region

3.0 LOAD DEFINITIONS

The pressure and thermal stresses for the feedwater nozzle for the revised fatigue evaluation were developed using the axisymmetric FEM model described in Section 2.0 of this report. The details of the Green's function development and associated stress evaluation are documented in the Reference [10] calculation.

3.1 Thermal Loading

Thermal loads are applied to the feedwater nozzle model. The heat transfer coefficients after power uprate were determined in Reference [10]. These values were determined for various regions of the finite element model and for 100% (4,590 GPM), 40% (1836 GPM) and 25% (1,148 GPM) [10]. The annulus leakage flow rate is assumed to be 25 GPM for non-EPU conditions and 31 GPM for EPU conditions. The 25 GPM value is calculated by scaling the 23 GPM [Page 6, 13] value up by approximately 9%. The 23 GPM value is scaled up to provide some conservatism and allow for inaccuracies in the determination of leakage flow. The 31 GPM value is calculated by multiplying the 25 GPM value by 1.25 [Page 6, 13]. Based on this, the annulus leakage flow rate is assumed to be 8 GPM for EPU conditions with 25% flow rate and 13 GPM for EPU condition with 40% flow rate. The temperatures used are based upon a thermal shock from 500°F to 100°F.

3.1.1 Heat Transfer Coefficients and Boundary Fluid Temperatures

Referring to Figure 3-4, heat transfer coefficients were applied as follows:

- The heat transfer coefficient for the outside surfaces of the FEM (Region 8) was a constant value of 0.2 BTU/hr-ft^2-°F (3.858×10^{-7} BTU/sec-in^2-°F).
- Table 3-3 shows a sampling of the heat transfer coefficient calculations for Region 1 for the 40% flow case.

For all Green's Functions, a 500°F to 100°F thermal shock was run to determine the stress response.

The applied heat transfer coefficients and the initial temperatures for all regions are contained in Reference [10].

3.1.2 Green's Function's

Three flow dependent thermal load cases were run on the FEM model with the heat transfer coefficients and the fluid temperature conditions listed above. Two locations were selected for analysis (see Figures 3-5 and 3-6):

1. The critical safe end location was chosen as the node with the highest stress intensity due to thermal loading under high flow conditions. The highest stress intensity due to thermal loading occurred at Node 192 (see Figure 3-5), on the inside diameter of the nozzle safe end, and therefore, this node was selected for analysis. Because the safe end stress response is affected by flow, three flow conditions were analyzed (100%, 40% and 25%).
2. The critical blend radius location was chosen, based upon the highest pressure stress. Conservatively assuming the cladding has cracked, the critical location is selected as node 657 at base metal of the nozzle, as shown in Figure 3-6. Because the blend radius stress response is affected by flow, three flow conditions were analyzed (100%, 40% and 25%).

Two stress intensity time history were developed for each location and each flow case: (1) total stress intensity, and (2) membrane plus bending stress intensity. The stress time histories for the safe end location, where the maximum stress was obtained for each of the flow conditions, are shown in Figures 3-7 through 3-12. The stress time histories for the blend radius location, where the maximum stress was obtained for each of the flow conditions, are shown in Figures 3-13 through 3-18.

3.1.3 *Thermal Transients (for program STRESS.EXE)*

The program STRESS.EXE requires the following three input files for analyzing an individual transient:

- Green.dat. There are 12 stress history functions obtained from Reference [10]. They represent the membrane plus bending and total stress intensities at the blend radius and safe end locations. Both of the blend radius and the safe end have two stress history functions for each of the following flow conditions; 100%, 40%, and 25% flow.
- Green.cfg is configured as described in Reference [14].
- Transnt.inp. These files are created to represent the transients shown on the thermal cycle diagrams and redefined by power uprate. Note that transients 12, 13, and 15 are nearly identical on the thermal cycle diagram [19] and the results from running transient 12 will be used for all three transients. Transient 16, 17 and 18 will not be considered since there is no temperature change. Tables 3-4 and 3-5 show the thermal history used to represent each transient. Based upon the thermal cycle diagram for the feedwater nozzle [19], the transients are split into the following groups based upon flow rate:
    - Transients 3, 20, 20A, and 21-23 are run at 25% flow. Although Reference [19] shows 15% flow rate, it is conservative to use 25% flow rate for these transients. Transient 20, Hot Standby, is split up into two parts. The first portion is "Heatup portion" and the second portion is "Feedwater Injection portion" that are defined from Reference [19].
    - Transient 11 is run at 40% flow. Transient 11 starts off and ends at 100% flow.
    - Transients 5, 6, 9, 10, and 19 are run at 100% flow.
    - Transient 4 is run at 100% flow only to obtain the last stress point. The remainder of the stress points for transient 4 is obtained from the 25% flow stress results. The results are pulled from the two flow case results based upon the flow rates defined in the thermal cycle diagram [19].
    - Transients 12, 13, 14 and 15 were run at 100% flow. Heat transfer coefficients were not re-calculated for the 1 minute intervals each of these transients is at 110% flow. The effect of this small flow rate increase for such a relatively short duration should be minor.

- Transients 1, 2, 24, and 25 are set as no thermal stress due to very small temperature changes (70°F to 100°F) at these transients.

3.2 Pressure Loading

A uniform pressure of 1,000 psi was applied along the inside surface of the feedwater nozzle and the vessel wall. A pressure load of 1,000 psi was used because it is easily scaled up or down to account for different pressures that occur during transients. In addition, a cap load was applied to the piping at the end of the nozzle. The nodal forces shown in Table 3-1 [10] are defined by the following equation:

$$F_{element} = \pi (IR)^2 P \cdot \frac{\pi\left(R_o^{\,2} - R_i^{\,2}\right)}{\pi\left(OR^2 - IR^2\right)}$$

where:	P	=	unit pressure load = 1,000 psi
	IR	=	inner pipe radius = 4.8345 in
	OR	=	outer pipe radius = 5.42 in
	R_i	=	inside radius of element that node is attached to
	R_o	=	outside radius of element that node is attached to
	F_{node}	=	average of the element forces on either side of the node.

Note: The force on the innermost and outermost nodes is calculated as one half of the force on the element that they are attached to.

The calculated nodal forces were applied as positive values so they would exert tension on the end of the model. Figures 3-1, 3-2, and 3-3 show the internal pressure distribution, cap load, and symmetry condition applied to the vessel end of the model, respectively.

The pressure stress associated with a 1000 psi internal pressure was determined in Reference [10]. These values are as follows:

Pressure stress for the safe end:

- 8693 psi membrane plus bending stress intensity.
- 8891 psi total linearized stress intensity.

Pressure stress for the blend radius:

- 36653 psi membrane plus bending stress intensity.
- 37733 psi total linearized stress intensity.

These pressure stress values for each location were linearly scaled with pressure. The actual pressure for column 6 of Tables 4-1 and 4-2 is obtained from Tables 3-4 and 3-5. The scaled pressure stress values are shown in columns 7 and 8 of Tables 4-1 and 4-2.

The pressure stress is combined with the thermal and piping loads to calculate the final stress values used for fatigue analysis. The piping load sign is set as the same as the thermal stress sign.

3.3 Piping Loading

Additionally, the piping stress intensity (stress caused by the attached piping) was determined. These piping forces and moments are determined as shown in Figure 3-36.

The following formulas are used to determine the maximum stress intensity in the nozzle at the two locations of interest. From engineering statics, the piping loads at the end of the model can be translated to the first and second cut locations using the following equations:

For Cut I:
$$(M_x)_1 = M_x - F_y L_1$$
$$(M_y)_1 = M_y + F_x L_1$$

For Cut II:
$$(M_x)_2 = M_x - F_y L_2$$
$$(M_y)_2 = M_y + F_x L_2$$

The total bending moment and shear loads are obtained using the equations below:

For Cut I:

$$M_{xy} = \sqrt{(M_x)_1^2 + (M_y)_1^2}$$
$$F_{xy} = \sqrt{(F_x)_1^2 + (F_y)_1^2}$$

For Cut II:

$$M_{xy} = \sqrt{(M_x)_2^2 + (M_y)_2^2}$$
$$F_{xy} = \sqrt{(F_x)_2^2 + (F_y)_2^2}$$

The distributed loads for a thin-walled cylinder are obtained using the equations below:

$$N_z = \frac{1}{\pi R_N}\left[\frac{1}{2}F_z + \frac{M_{xy}}{R_N}\right]$$
$$q_N = \frac{1}{\pi R_N}\left[F_{xy} - \frac{M_z}{2R_N}\right]$$

To determine the primary stresses, P_M, due to internal pressure and piping loads, the following equations are used.

For Cut I, using thin-walled equations:

$$(P_M)_z = \frac{Pa_N}{2t_N} + \frac{Nz}{t_N}$$

$$(P_M)_\theta = \frac{Pa_N}{t_N}$$

$$(P_M)_R = -P$$

$$\tau_M = \frac{q_N}{t_N}$$

$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_\theta - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^{\ 2}}$$

or

$$SI_{MAX} = 2\sqrt{\left(\frac{(P_M)_z - (P_M)_R}{2}\right)^2 + (\tau_M)_{z\theta}^{\ 2}}$$

where:

L_1 = The length from the end of the nozzle where the piping loads are applied to the location of interest in the safe end.

L_2 = The length from the end of the nozzle where the piping loads are applied to the location of interest in the blend radius.

M_{xy} = The maximum bending moment in the xy plane.

F_{yx} = The maximum shear force in the xy plane.

N_z = The normal force per inch of circumference applied to the end of the nozzle in the z direction.

q_N = The shear force per inch of circumference applied to the nozzle.

R_N = The mid-wall nozzle radius.

Because pressure was not considered in this analysis, the equations used for Cut I are valid for Cut II. Furthermore, since the pressure was not considered in this analysis, the equations can be simplified as follows:

$$(P_M)_z = \frac{Nz}{t_N}$$

$$(P_M)_\theta = 0$$

$$(P_M)_R = 0$$

$$\tau_M = \frac{q_N}{t_N}$$

$$SI_{MAX} = 2(\tau_M)_{z\theta}$$

or

$$SI_{MAX} = 2\sqrt{\left(\frac{Nz}{2t_N}\right)^2 + (\tau_M)_{z\theta}^{\ 2}}$$

Per Reference [11], the feedwater nozzle piping loads are as follows:

F_x = 3,000 lbs	M_x = 28,000 ft-lb = 336,000 in-lb
F_y = 15,000 lbs	M_y = 13,000 ft-lb = 156,000 in-lb
F_z = 3,200 lbs	M_z = 40,000 ft-lb = 480,000 in-lb

The loads are applied at the connection of the piping and safe end. Therefore, the L_1 is equal to 12.0871 inches and the L_2 is equal to 27.572 inches. The calculations for the safe end and blend radius are shown in Table 3-2. The first cut location is the same as the Green's Function cross section per [10] at the safe end, and the second cut is from Node 645 (outside) to Node 501 (inside). The maximum stress intensities due to piping loads are 5707.97 psi at the safe end and 265.47 psi at the blend radius, respectively.

These piping stress values are scaled assuming no stress occurs at an ambient temperature of 70°F and the full values are reached at reactor design temperature, 575°F. The scaled piping stress values are shown in columns 9 and 10 of Tables 4-1 and 4-2. Columns 11 and 12 of Tables 4-1 and 4-1 show the summation of all stresses for each thermal peak and valley stress point.

Table 3-1: Nodal Force Calculation for End Cap Load

Node Number	Element Number	Radius (in)	Δ Radius (in)	R_o^2-Ri^2 (in^2)	$F_{element}$ (lb)	F_{node} (lb)
1		5.42				7678.0
	1022		0.1171	1.25565	15356.1	
2		5.3029				15188.4
	1021		0.1171	1.22823	15020.7	
3		5.1858				14853.0
	1020		0.1171	1.20080	14685.3	
4		5.0687				14517.6
	1019		0.1171	1.17338	14349.9	
5		4.9516				14182.2
	1018		0.1171	1.14595	14014.5	
6		4.8345				7007.3

Table 3-2: Maximum Piping Stress Intensity Calculations

Safe End External Piping Loads		
Parameters		
F_x =	3.00	kips
F_y =	15.00	kips
F_Z =	3.20	kips
M_x =	336.00	in-kips
M_y =	156.00	in-kips
M_Z =	480.00	in-kips
OD=	11.86	in
ID=	10.409	in
R_N =	5.57	in
L =	12.09	in
t_N =	0.72	in
$(M_x)_1$ =	154.69	in-kips
$(M_y)_1$ =	192.26	in-kips
M_{xy} =	246.77	in-kips
F_{xy} =	15.30	kips
N_Z =	2.63	kips/in
q_N =	-1.59	kips/in
Primary Membrane Stress Intensity		
PM_Z =	3.63	ksi
τ =	-2.20	ksi
SI_{max} =	5.71	ksi
SI_{max} =	5707.97	psi

Blend Radius External Piping Loads		
Parameters		
F_x =	3.00	kips
F_y =	15.00	kips
F_Z =	3.20	kips
M_x =	336.00	in-kips
M_y =	156.00	in-kips
M_Z =	480.00	in-kips
OD=	22.67	in
ID=	10.750	in
R_N =	8.35	in
L =	27.57	in
t_N =	5.96	in
$(M_x)_2$ =	-77.58	in-kips
$(M_y)_2$ =	238.72	in-kips
M_{xy} =	251.01	in-kips
F_{xy} =	15.30	kips
N_Z =	1.21	kips/in
q_N =	-0.51	kips/in
Primary Membrane Stress Intensity		
PM_Z =	0.20	ksi
τ =	-0.09	ksi
SI_{max} =	0.27	ksi
SI_{max} =	265.47	psi

Note: The locations for Cut I and Cut II were defined in Reference [10] for safe end and blend radius paths, respectively.

Table 3-3: Heat Transfer Coefficients for Region 1 (40% Flow)

Calculation of Heat Transfer Coefficients for Feedwater Nozzle Flow Path

Pipe Inside Diameter, D =	9.669	inches =	0.806	ft		100% rated flow =	4,590	gpm
		=	0.246	m		@ T =	391.9	°F
Flow, % of rated =	40%					Density, ρ =	53.8997	lbm/ft³
Fluid Velocity, V =	8.022	ft/sec =	1,836.0	gpm =		0.793742524	Mlb/hr	
Characteristic Length, L = D =	0.806	ft =	0.246	m				

$T_{fluid} - T_{surface}$, ΔT = assumed to be 12% of fluid temperature =	8.40	12.00	24.00	36.00	48.00	60.00	72.00	°F
Note: The above assumption is based on experience with past RPV heat transfer analyses. =	4.67	6.67	13.33	20.00	26.67	33.33	40.00	°C

Water Property	Conversion Factor [24]	Value at Fluid Temperature, T [26] 70 21.11	100 37.78	200 93.33	300 148.89	400 204.44	500 260.00	600 315.56	Units °F °C
k (Thermal Conductivity)	1.7307	0.5997	0.6300	0.6784	0.6836	0.6611	0.6040	0.5071	W/m-°C
		0.3465	0.3640	0.3920	0.3950	0.3820	0.3490	0.2930	Btu/hr-ft-°F
c_p (Specific Heat)	4.1869	4.185	4.179	4.229	4.313	4.522	4.982	6.322	kJ/kg-°C
		1.000	0.998	1.010	1.030	1.080	1.190	1.510	Btu/lbm-°F
ρ (Density)	16.018	997.1	994.7	962.7	917.8	858.6	784.9	679.2	kg/m³
		62.3	62.1	60.1	57.3	53.6	49.0	42.4	lbm/ft³
β (Volumetric Rate of Expansion)	1.8	1.89E-04	3.24E-04	6.66E-04	1.01E-03	1.40E-03	1.98E-03	3.15E-03	m³/m³-°C
		1.05E-04	1.80E-04	3.70E-04	5.60E-04	7.80E-04	1.10E-03	1.75E-03	ft³/ft³-°F
g (Gravitational Constant)	0.3048	9.806	9.806	9.806	9.806	9.806	9.806	9.806	m/s²
		32.17	32.17	32.17	32.17	32.17	32.17	32.17	ft/s²
μ (Dynamic Viscosity)	1.4881	9.96E-04	6.82E-04	3.07E-04	1.93E-04	1.38E-04	1.04E-04	8.62E-05	kg/m-s
		6.69E-04	4.58E-04	2.06E-04	1.30E-04	9.30E-05	7.00E-05	5.79E-05	lbm/ft-s
Pr (Prandtl Number)		6.980	4.510	1.910	1.220	0.950	0.859	1.070	---
Calculated Parameter	**Formula**	70	100	200	300	400	500	600	°F
Reynold's Number, Re	ρVD/μ	6.0147E+05	8.7645E+05	1.8859E+06	2.8491E+06	3.7255E+06	4.5248E+06	4.7336E+06	---
Grashof Number, Gr	$g\beta\Delta TL^3/(\mu/\rho)^2$	1.2852E+08	6.6834E+08	1.2721E+10	6.5918E+10	2.0931E+11	5.4429E+11	1.1372E+12	---
Rayleigh Number, Ra	GrPr	8.9710E+08	3.0142E+09	2.4297E+10	8.0420E+10	1.9885E+11	4.6755E+11	1.2168E+12	---
From [24]: *Inside Surface Forced Convection Heat Transfer Coefficient:*									
H_{forced} =	$0.023Re^{0.8}Pr^{0.4}k/D$	5,132.76	6,119.10	8,626.61	10,107.53	10,960.57	11,236.63	10,678.39	W/m²-°C
		903.95	1,077.66	1,519.26	1,780.07	1,930.31	1,978.92	1,880.61	Btu/hr-ft²-°F
		1.744E-03	2.079E-03	2.931E-03	3.434E-03	3.724E-03	3.817E-03	3.628E-03	Btu/sec-in²-°F
From [24]: *Inside Surface Natural Convection Heat Transfer Coefficient:*									
Case:	Enclosed cylinder		C =	0.55	n =	0.25	(see page 289 of [25])		
H_{free} =	$C(GrPr)^n k/L$	232.43	330.57	599.85	815.28	988.69	1,118.54	1,192.73	W/m²-°C
		40.93	58.22	105.64	143.58	174.12	196.99	210.06	Btu/hr-ft²-°F
		7.896E-05	1.123E-04	2.038E-04	2.770E-04	3.359E-04	3.800E-04	4.052E-04	Btu/sec-in²-°F

Table 3-4: Blend Radius Transients

Transient Number	Time (s)	Temp (°F)	Time Step (s)	Pressure (psig)
1. Bolt-up	0	70		0
123 Cycles	10	70	10	0
2. Design	0	70		0
HYD Test	1080	100	1080	0
120 Cycles	1680	100	600	1100
	5280	100	3600	1100
	5880	100	600	50
	10880	100	5000	50
3. Startup	0	100		50
300 Cycles	16164	549	16164	1010
LF_25	21164	549	5000	1010
4. Turbine Roll	*0*	549		1010
and Increased to	1	100	1	1010
Rated	1801	100	1800	1010
Power	1802	260	1	1010
300 cycles	3602	392	1800	1010
LF_25, HF_100	8602	392	5000	1010
5. Daily	0	392		1010
Reduction	900	310	900	1010
75% Power	2700	310	1800	1010
10,000 Cycles	3600	392	900	1010
HF_100	8600	392	5000	1010
6. Weekly Reduct	0	392		1010
50% Power	1800	280	1800	1010
2,000 Cycles	3600	280	1800	1010
HF_100	5400	392	1800	1010
	10400	392	5000	1010
9. Turbine	0	392		1010
Trip at 25%	1800	265	1800	1010
Power	1980	265	180	1010
10 Cycles	2340	90	360	1010
HF_100	2520	90	180	1010
	3420	265	900	1010
	3600	265	180	1010
	5400	392	1800	1010
	10400	392	5000	1010

Transient Number	Time (s)	Temp (°F)	Time Step (s)	Pressure (psig)
10. FW Heater	0	392		1010
Bypass	50	265	90	1010
70 Cycles	1890	265	1800	1010
HF_100	2070	392	180	1010
	7070	392	5000	1010
11. Loss of	0	392		1010
FW Pumps	1	565	1	1010
10 Cycles	3.5	565	2.5	1190
MF_40, HF_100	4.5	50	1	1185
	13.5	50	9	1135
	184.5	50	171	1135
	1564.5	440	1380	1135
	1565.5	565	1	1135
	2165.5	565	600	1135
	2166.5	50	1	1135
	2346.5	50	180	885
	5406.5	440	3060	1055
	5407.5	565	1	1055
	6727.5	565	1320	1135
	6728.5	50	1	1135
	7148.5	50	420	675
	7448.5	300	300	675
	11048.5	400	3600	232
	16411.5	549	5363	885
	16412.5	549	1	1010
	18212.5	549	1800	1010
	18213.5	100	1	1010
	20013.5	100	1800	1010
	20014.5	260	1	1010
	21814.5	392	1800	1010
	26814.5	392	5000	1010
12. Turbine	0	392		1010
Generator Trip	10	392	*10*	1135/1375[(2)]
60 Cycles	15	392	*5*	1135/1375[(2)]
13. Reactor	30	392	15	940
Overpressure	90	275	60	940
1 Cycles	990	100	900	940
15. Other	2790	100	1800	940
SCRAMs	2791	260	1	940
228 cycles	3210	291	419	1010
HF_100	4591	392	1381	1010
	9591	392	5000	1010

Transient Number	Time (s)	Temp (°F)	Time Step (s)	Pressure (psig)
14. SRV	0	392		1010
Blowdown	60	275	60	885
1 Cycles	960	100	900	50
HF_100	5960	100	5000	50
19. Reduction to 0%	0	392		1010
Power 300 Cycles	1800	265	1800	1010
HF_100	6800	265	5000	1010
20. Hot Standby	0	265		1010
(Heatup Portion)	1	440	1	1010
300 Cycles	3925	549	3924	1010
LF_25	8925	549	5000	1010
20A. Hot Standby	0	549		1010
(FW Injection Portion)	1	100	1	1010
300 Cycles	181	100	180	1010
LF_25	241	280	60	1010
	451	549	210	1010
	5451	549	5000	1010
21-23. Shutdown	0	549		1010
300 Cycles	6264	375	6264	50
LF_25	6864	330	600	50
	15144	100	8280	50
	20144	100	5000	50
24. Hydrostatic	0	100		50
Test	600	100	600	1563
1 Cycles	1200	100	600	1563
	1800	100	600	50
	2400	100	600	50
25. Unbolt	0	100		0
123 Cycles	1080	70	1080	0
	6080	70	5000	0

Note: 1. The indicated time or pressure was assumed.
2. 1375 psi is for Transient 13 only.

Table 3-5: Safe End Transient

Transient Number	Time (s)	Temp (°F)	Time Step (s)	Pressure (psig)
1. Boltup	0	70		0
123 Cycles	10	70	10	0
2. Design	0	70		0
HYD Test	1080	100	1080	0
120 Cycles	1680	100	600	1100
	5280	100	3600	1100
	5880	100	600	50
	6380	100	500	50
3. Startup	0	100		50
300 Cycles	16164	549	16164	1010
LF_25	16664	549	500	1010
4. Turbine Roll	0	549		1010
and Increased to	1	100	1	1010
Rated	1301	100	1800	1010
Power	1902	260	1	1010
300 cycles	3302	392	1800	1010
LF_25, HF_100	4102	392	500	1010
5. Daily	0	392		1010
Reduction	900	310	900	1010
75% Power	2700	310	1800	1010
10,000 Cycles	3600	392	900	1010
HF_100	4100	392	500	1010
6. Weekly Reduct	0	392		1010
50% Power	1800	280	1800	1010
2,000 Cycles	3600	280	1800	1010
HF_100	5400	392	1800	1010
	5900	392	500	1010
9. Turbine	0	392		1010
Trip at 25%	1800	265	1800	1010
Power	1980	265	180	1010
10 Cycles	2340	90	360	1010
HF_100	2520	90	180	1010
	3420	265	900	1010
	3600	265	180	1010
	5400	392	1800	1010
	5900	392	500	1010

Transient Number	Time (s)	Temp (°F)	Time Step (s)	Pressure (psig)
10. FW Heater	0	392		1010
Bypass	90	265	90	1010
75 Cycles	1800	265	1800	1010
HF_100	2070	392	180	1010
	2570	392	500	1010
11. Loss of	0	392		1010
FW Pumps	1	565	1	1010
10 Cycles	3.5	565	2.5	1190
LF_40, HF_100	4.5	50	1	1185
	13.5	50	9	1135
	184.5	50	171	1135
	1564.5	440	1380	1135
	1565.5	565	1	1135
	2165.5	566	600	1135
	2166.5	50	1	1135
	2346.5	50	180	365
	5406.5	440	3060	1055
	5407.5	565	1	1055
	6727.5	565	1320	1135
	6728.5	50	1	1135
	7148.5	50	420	675
	7448.5	300	300	675
	11048.5	400	3600	232
	16411.5	549	5363	885
	16412.5	549	1	1010
	18212.5	549	1800	1010
	18213.5	100	1	1010
	20013.5	100	1800	1010
	20014.5	200	1	1010
	21814.5	392	1800	1010
	22314.5	392	500	1010
12. Turbine	0	392		1010
Generator Trip	10	392	10	1135/1375[3]
65 Cycles	15	392	5	1135/1375[3]
13. Reactor	30	392	15	940
Overpressure	90	275	60	940
1 Cycles	990	100	900	940
15. Other	2790	100	1800	940
SCRAMs	2791	260	1	940
228 cycles	3210	291	419	1010
HF_100	4591	392	1381	1010
	5091	392	500	1010

Transient Number	Time (s)	Temp (°F)	Time Step (s)	Pressure (psig)
14. SRV	0	392		1010
Blowdown	60	275	60	885
1 Cycles	960	100	900	50
HF_100	1460	100	500	50
19. Reduction to 0%	0	392		1010
Power 300 Cycles	1800	265	1800	1010
HF_100	2300	265	500	1010
20. Hot Standby	0	265		1010
(Heating Portion)	1	440	!	1010
300 Cycles	3925	549	3924	1010
LF_25	4425	549	500	1010
20A. Hot Standby	0	549		1010
(FW Injection Portion)	1	100	1	1010
300 Cycles	181	100	180	1010
LF_25	241	250	60	1010
	451	549	210	1010
	951	549	500	1010
21-22. Shutdown	0	549		1010
300 Cycles	6264	375	6264	50
LF_25	6864	330	600	50
	15144	100	8280	50
	15644	100	500	50
24. Hydrostatic	0	100		50
Test	600	100	600	1563
1 Cycles	1200	100	600	1563
	1800	100	600	50
	2400	100	600	50
25. Unbolt	0	100		0
123 Cycles	1080	70	1080	0
	1580	70	500	0

Note: 1. *These transients are the same as in Table 3-4 with the exception of the 500 second steady state time increment that is used. The transients in Table 3-4 are plotted using a 5000 second steady state increment. The difference is due to the length of the Green's Function for the safe end which is shorter compared to the blend Radius.*
2. *The indicated time or pressure was assumed.*
3. *1375 psi is for Transient 13 only.*

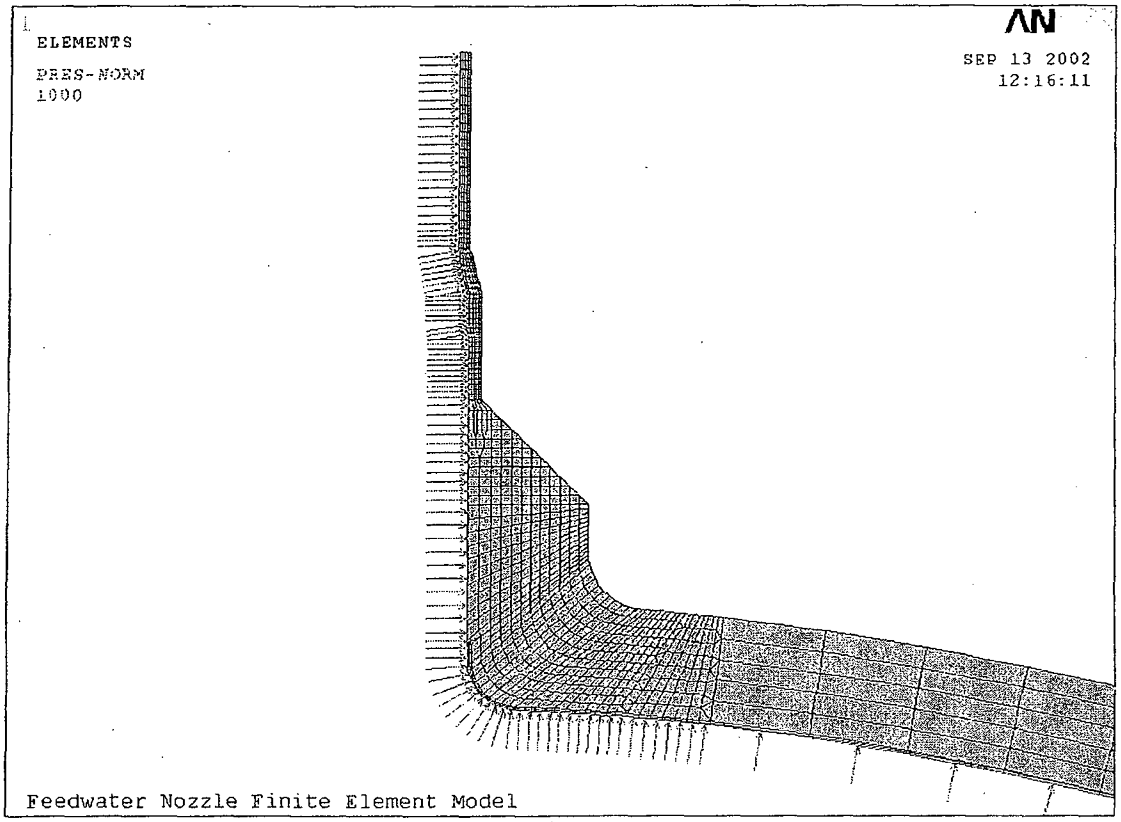


Figure 3-1: Feedwater Nozzle Internal Pressure Distribution

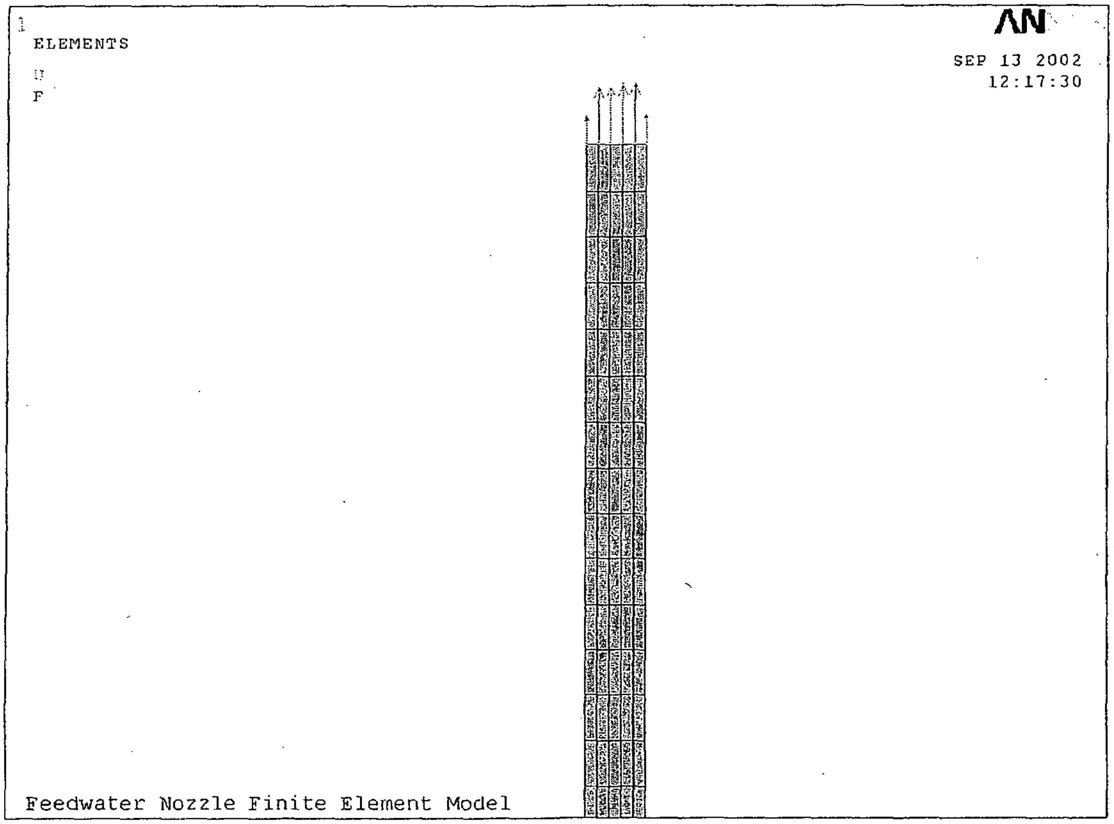


Figure 3-2: Feedwater Nozzle Pressure Cap Load

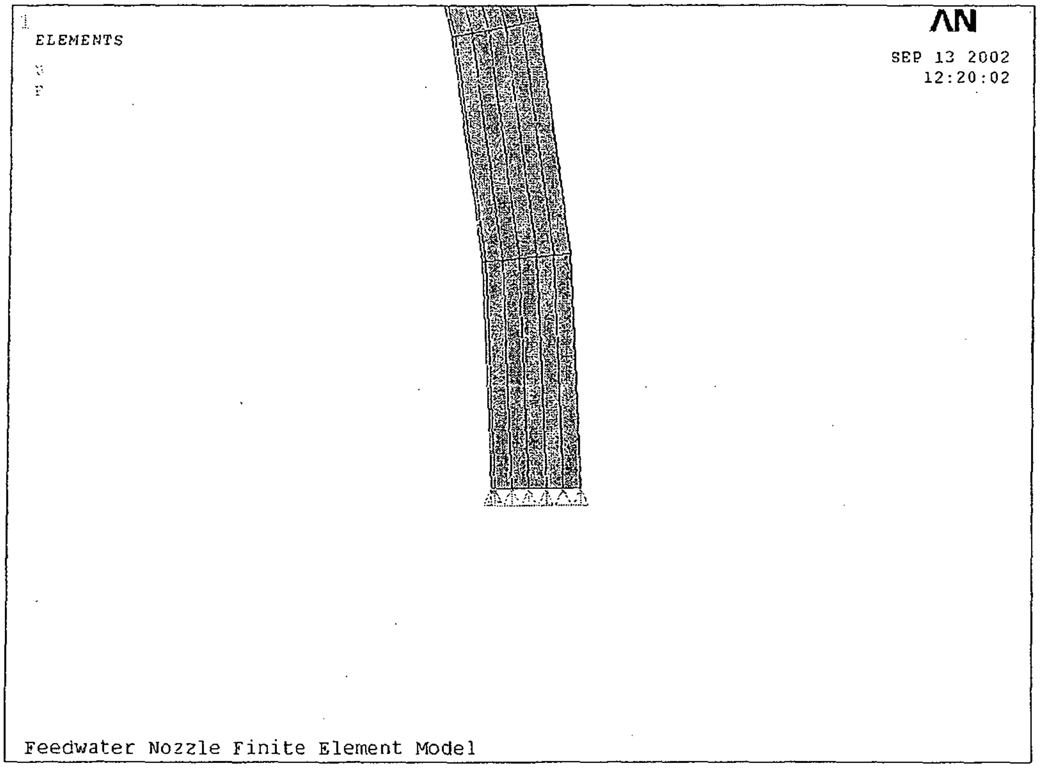
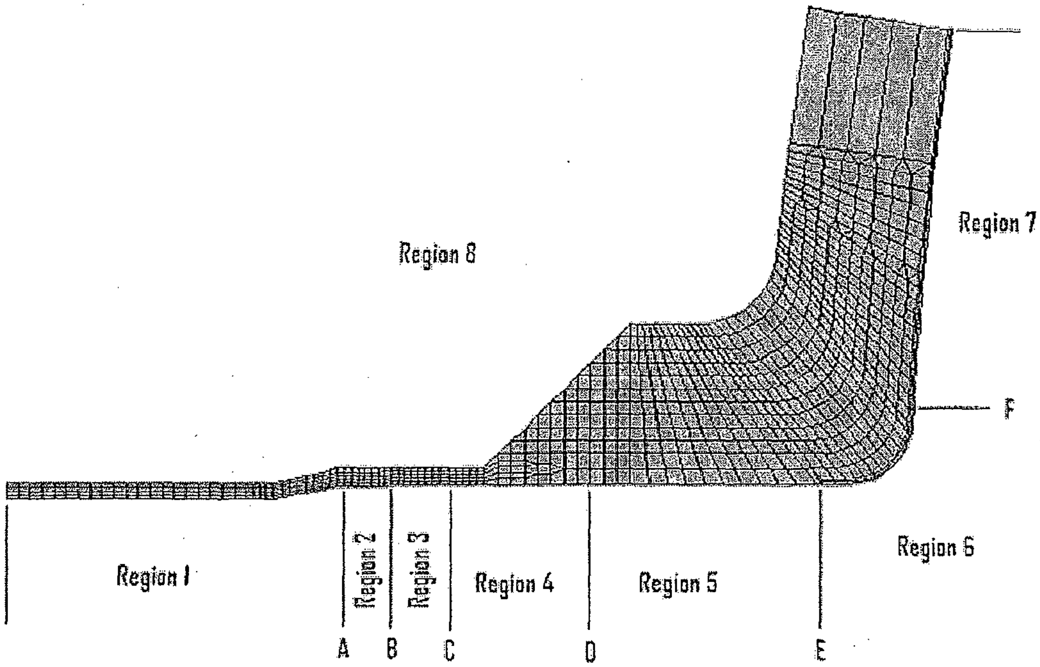


Figure 3-3: Feedwater Nozzle Vessel Boundary Condition



Notes: Point A: End of thermal sleeve = Node 204 = 0.25" from feedwater inlet side of thermal sleeve flat per Reference [8].
Point B: Beginning of annulus = Node 252.
Point C: Beginning of thermal sleeve transition = approximately 4.0" from Point A per Reference [8] = Node 294.
Point D: End of thermal sleeve transition = approximately 9.5" from Point A per Reference [8] = Node 387.
Point E: End of inner blend radius (nozzle side) = Node 553.
Point F: End of inner blend radius (vessel wall side) = Node 779.

Figure 3-4: Thermal Regions

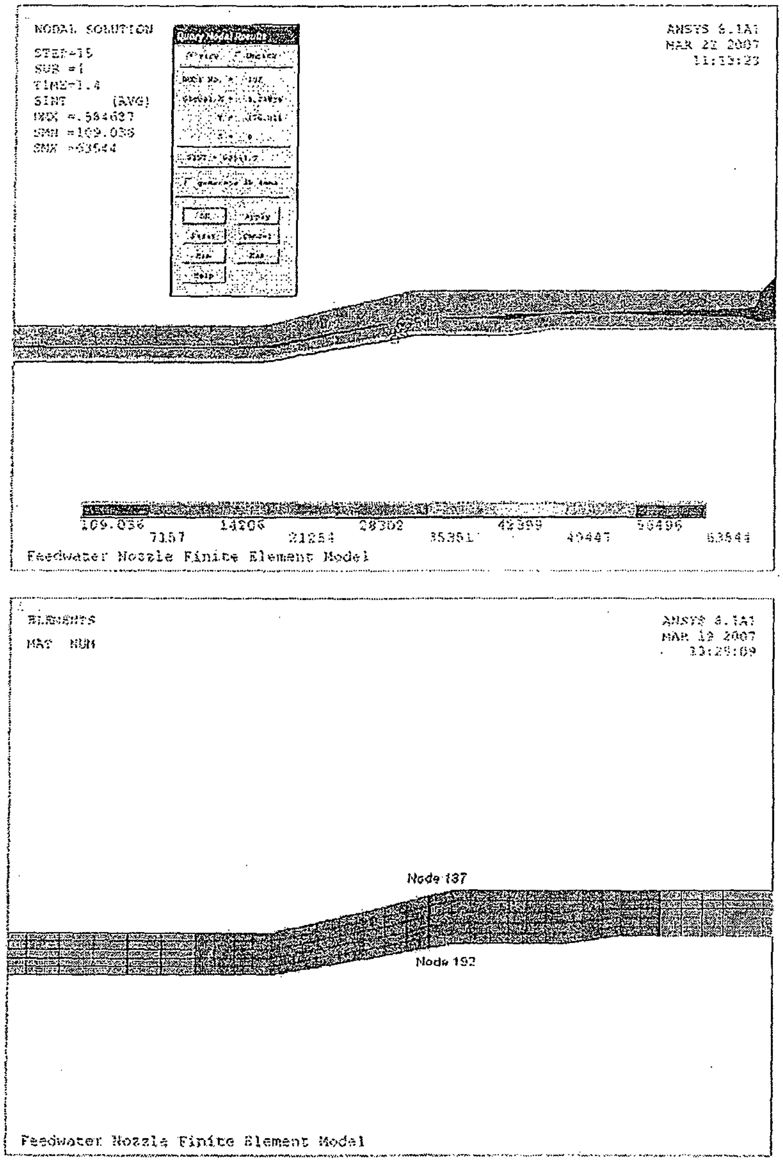
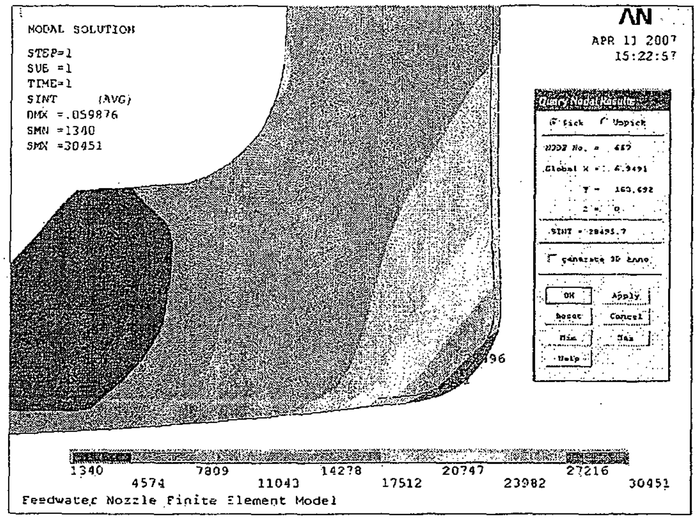


Figure 3-5: Safe End Critical Thermal Stress Location and Linearized Stress Paths



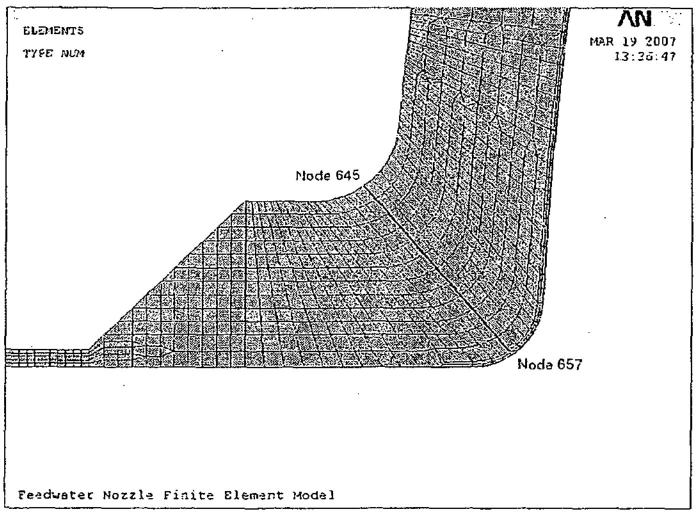


Figure 3-6: Brand Radius Critical Thermal Stress Location and Linearized Stress Paths

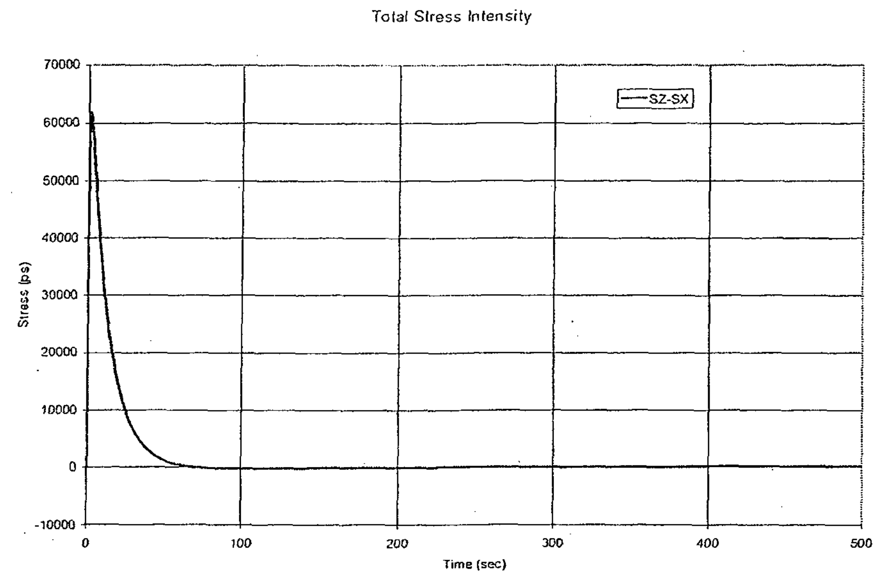


Figure 3-7: Safe End Total Stress History for 100% Flow

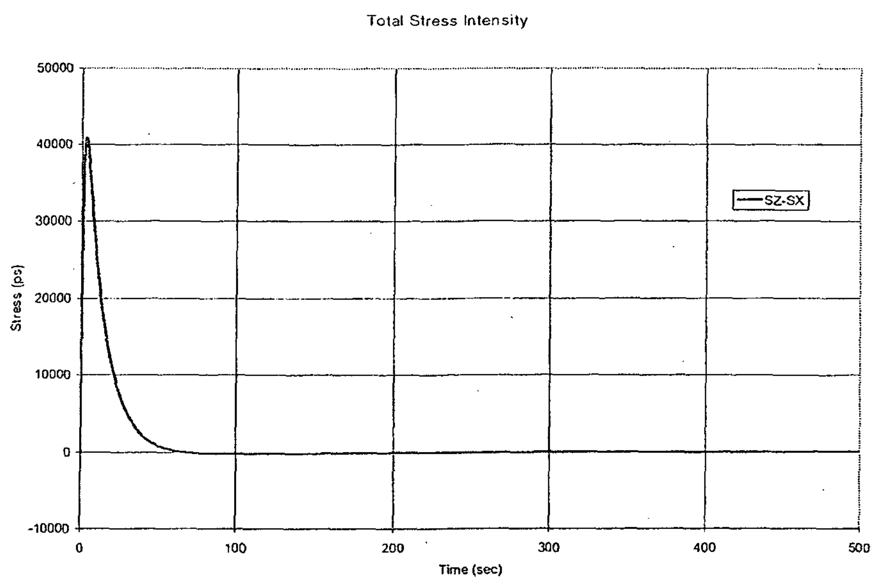


Figure 3-8: Safe End Membrane Plus Bending Stress History for 100% Flow

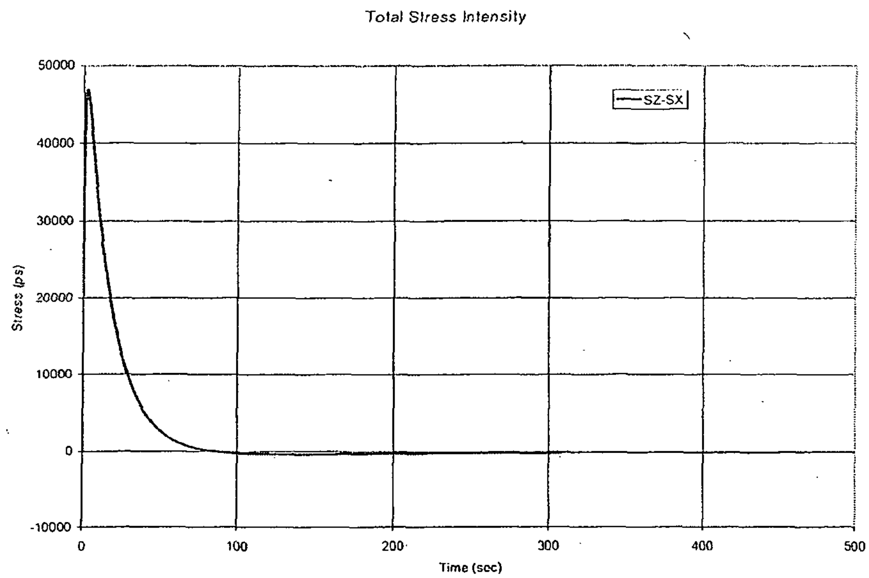


Figure 3-9: Safe End Total Stress History for 40% Flow

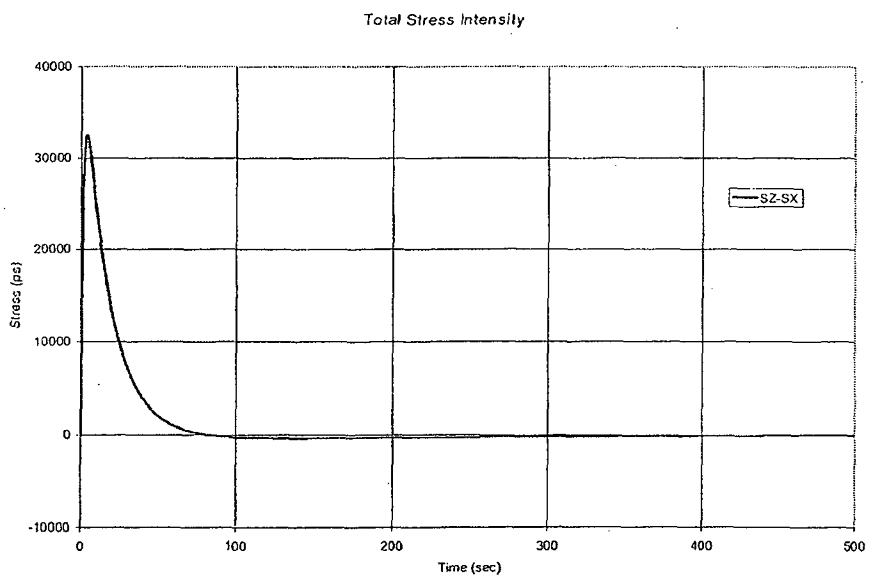


Figure 3-10: Safe End Membrane Plus Bending Stress History for 40% Flow

Total Stress Intensity

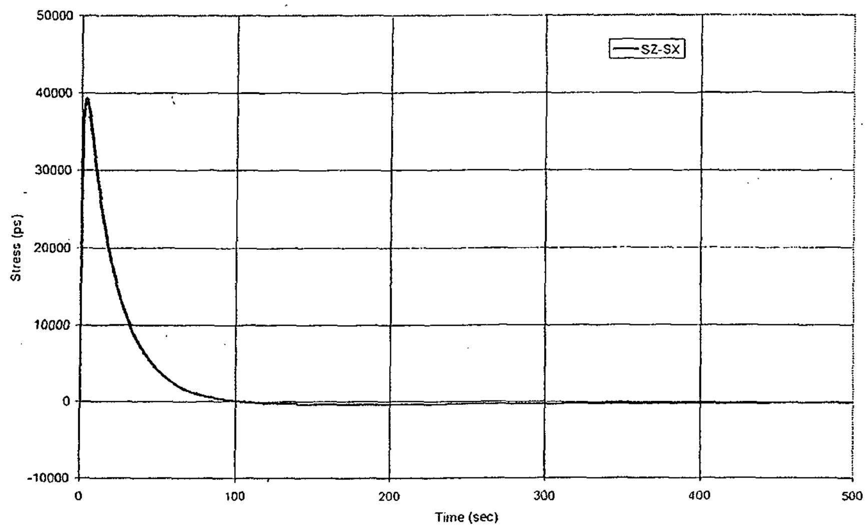


Figure 3-11: Safe End Total Stress History for 25% Flow

Total Stress Intensity

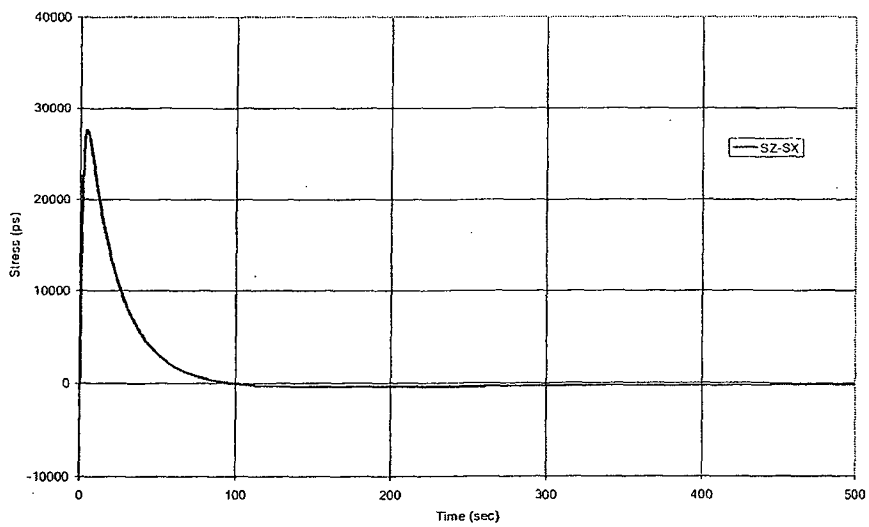


Figure 3-12: Safe End Membrane Plus Bending Stress History for 25% Flow

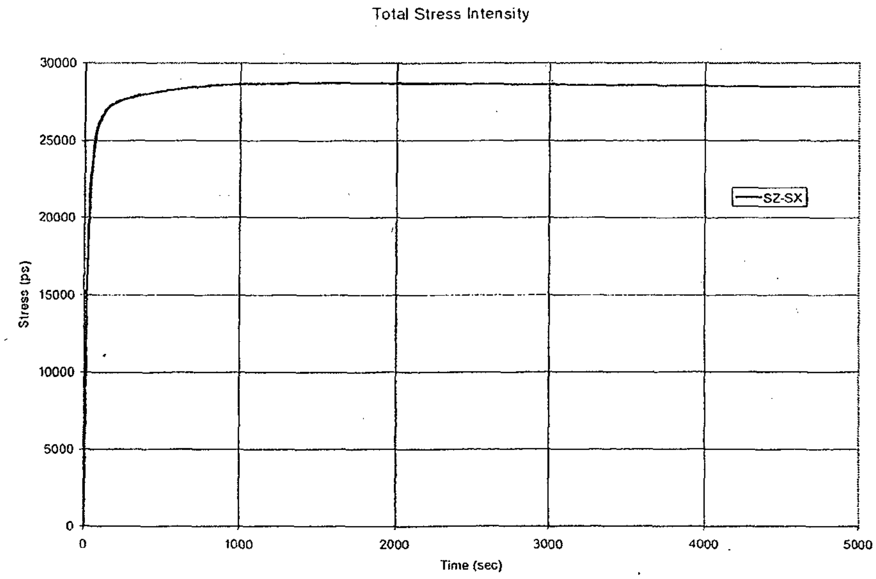


Figure 3-13: Blend Radius Total Stress History for 100% Flow

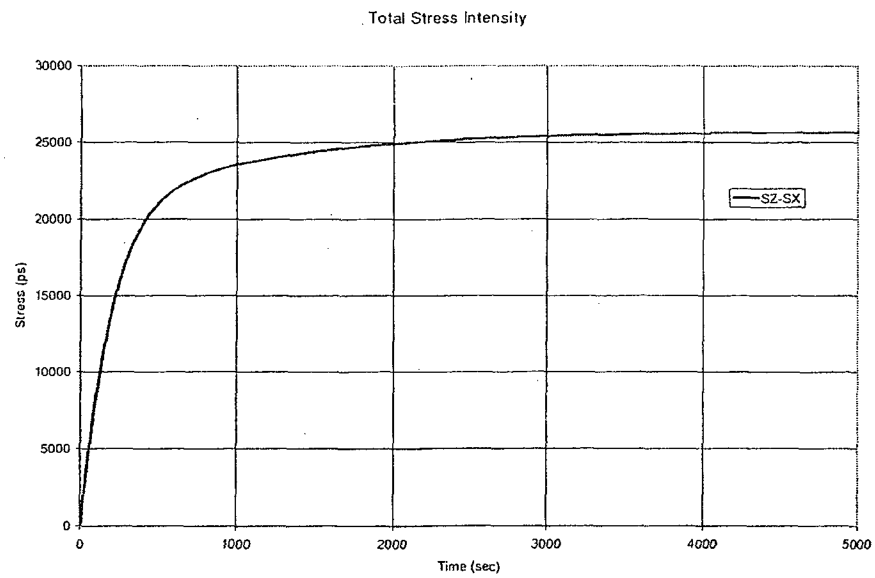


Figure 3-14: Blend Radius Membrane Plus Bending Stress History for 100% Flow

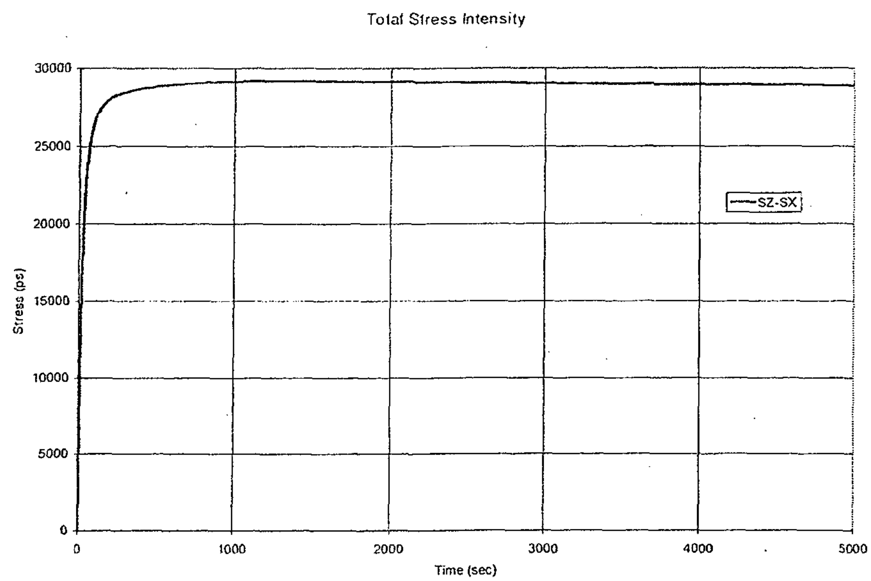


Figure 3-15: Blend Radius Total Stress History for 40% Flow

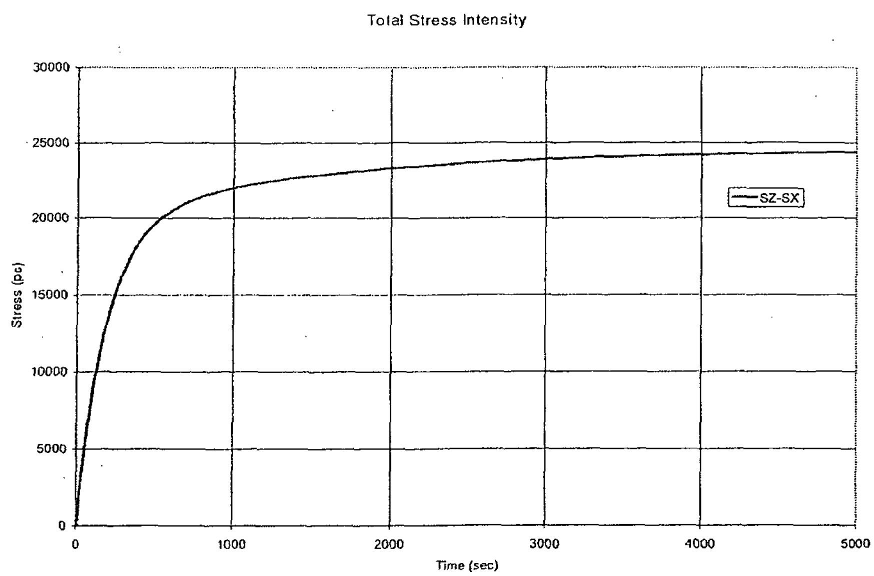


Figure 3-16: Blend Radius Membrane Plus Bending Stress History for 40% Flow

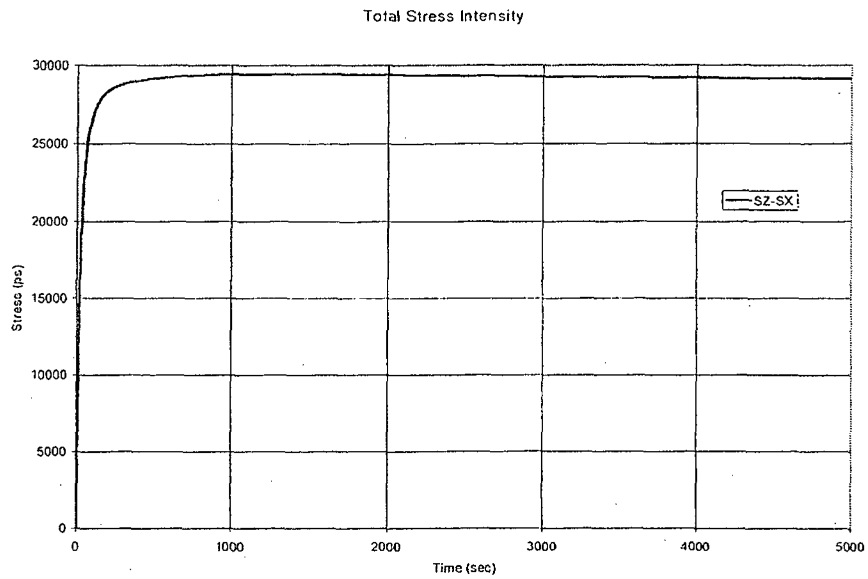


Figure 3-17: Blend Radius Total Stress History for 25% Flow

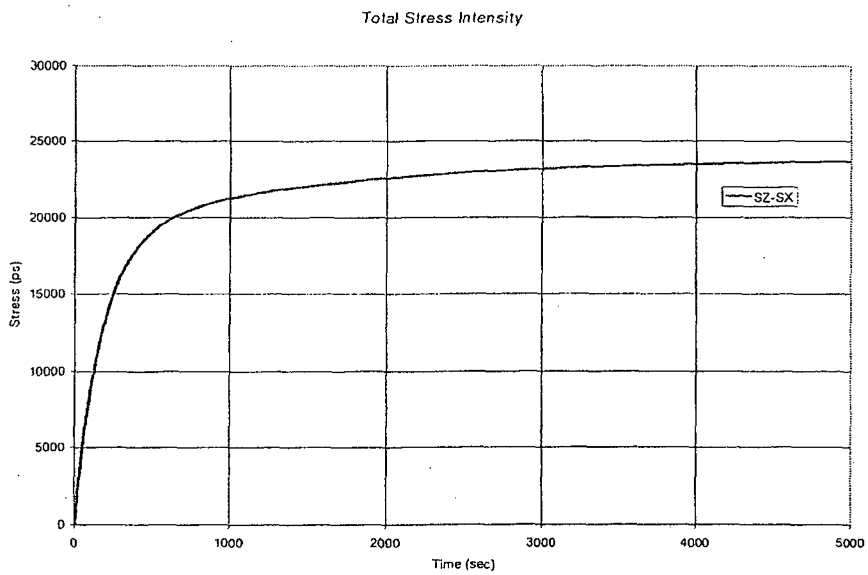


Figure 3-18: Blend Radius Membrane Plus Bending Stress History for 25% Flow

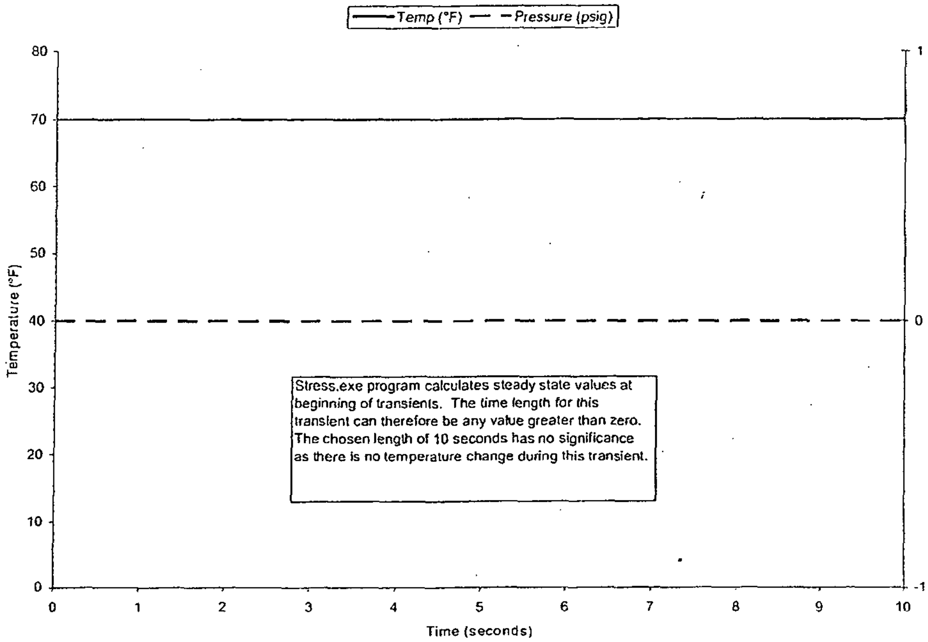


Figure 3-19: Transient 1, Bolt-up

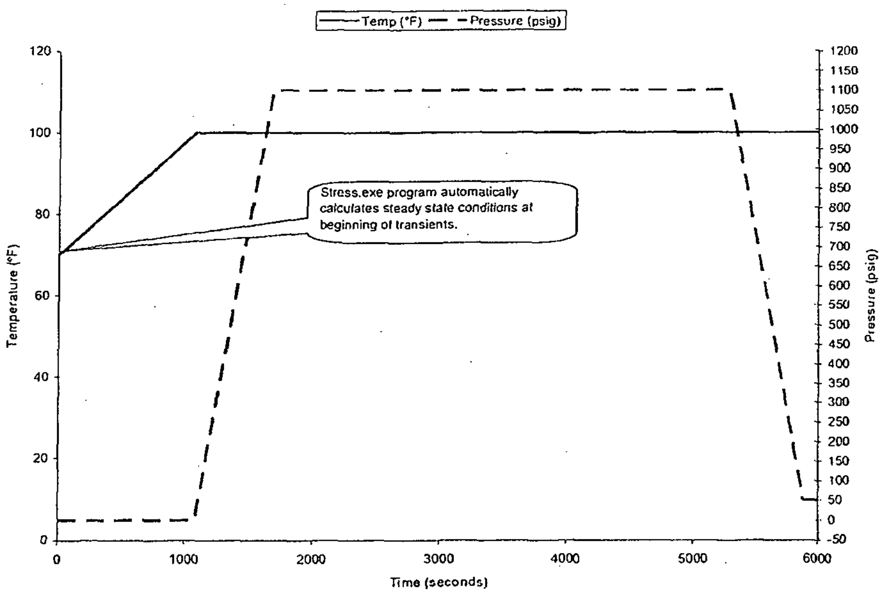


Figure 3-20: Transient 2, Design HYD Test

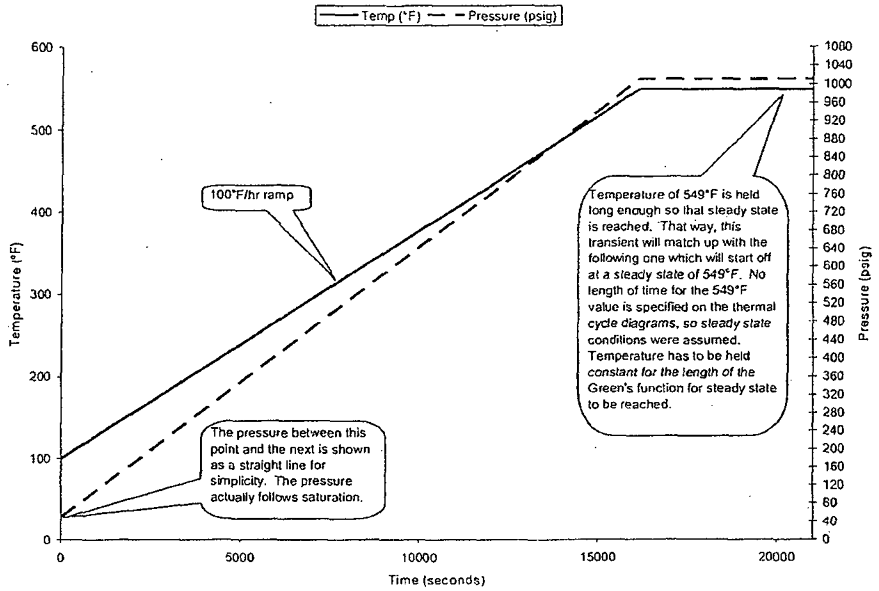


Figure 3-21: Transient 3, Startup

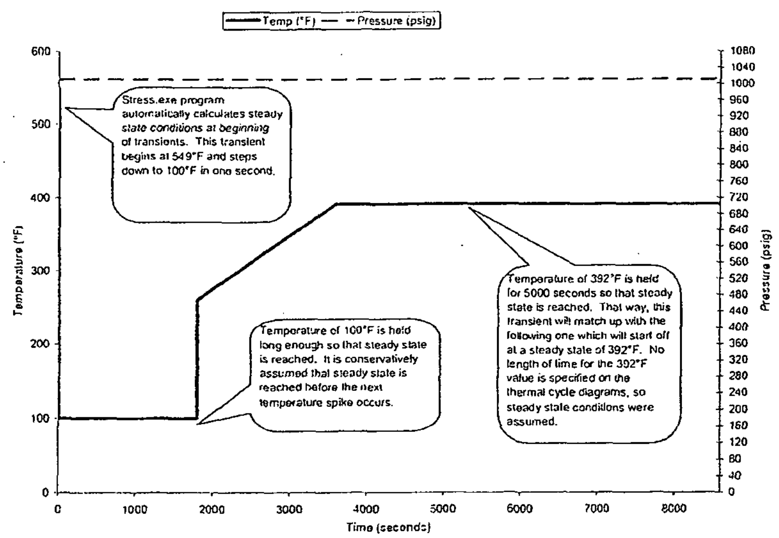


Figure 3-22: Transient 4, Turbine Roll and Increased to Rated Power

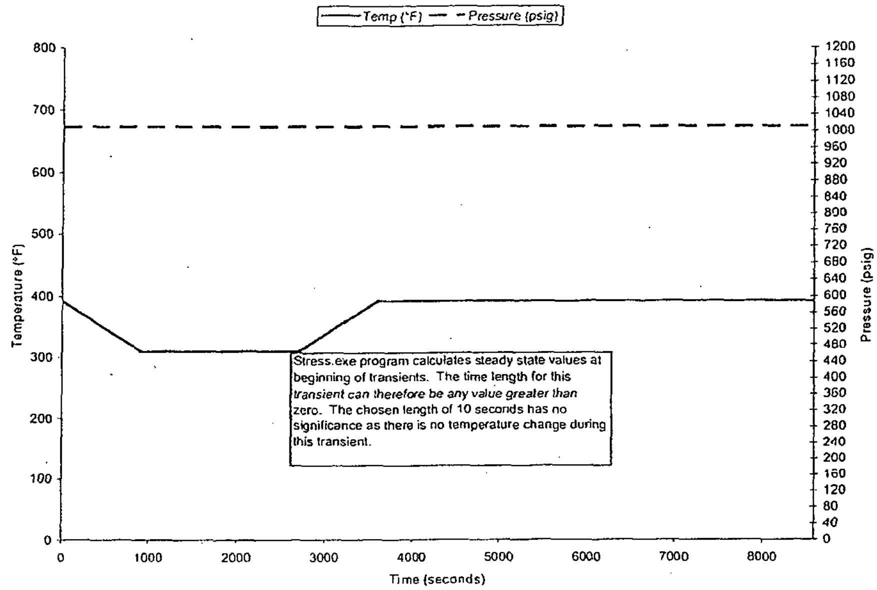


Figure 3-23: Transient 5, Daily Reduction 75% Power

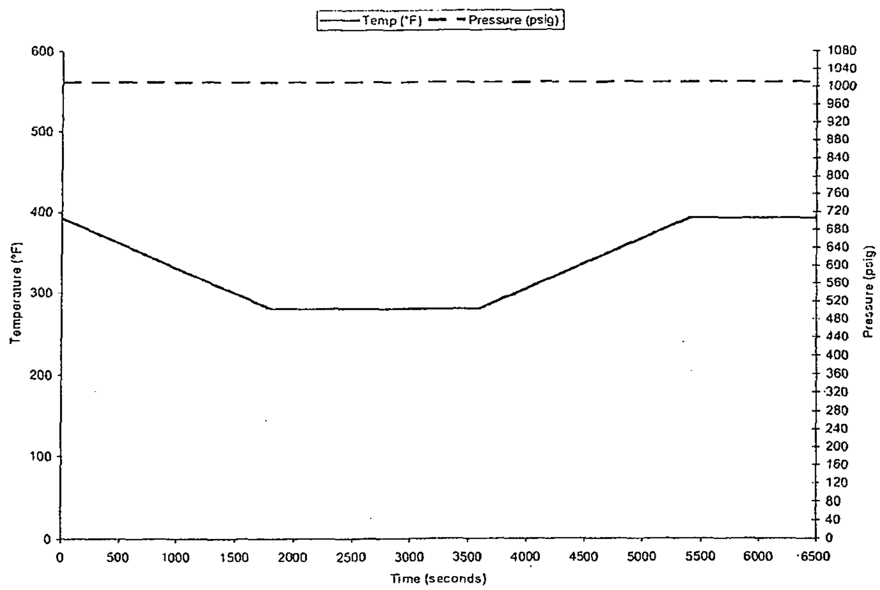


Figure 3-24: Transient 6, Weekly Reduction 50% Power

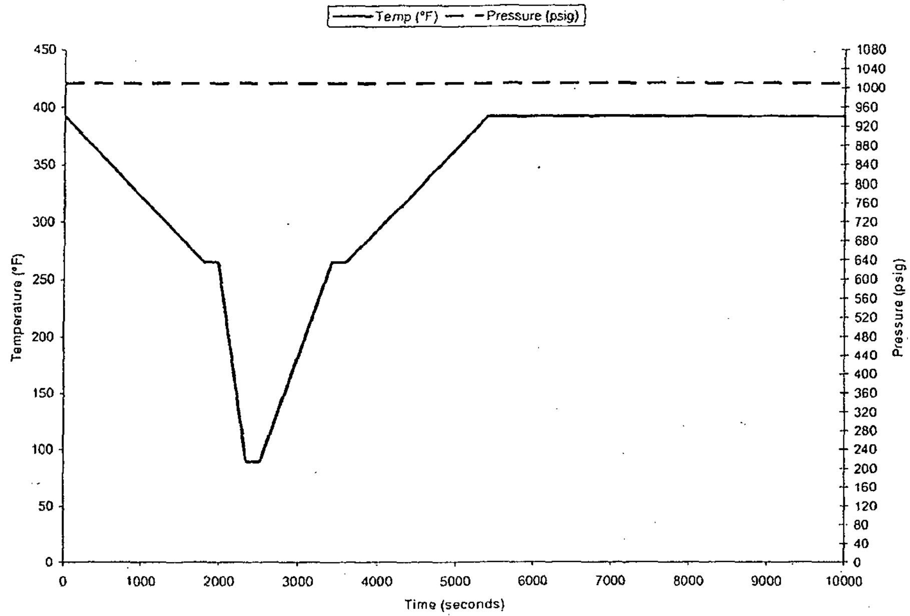


Figure 3-25: Transient 9, Turbine Trip at 25% Power

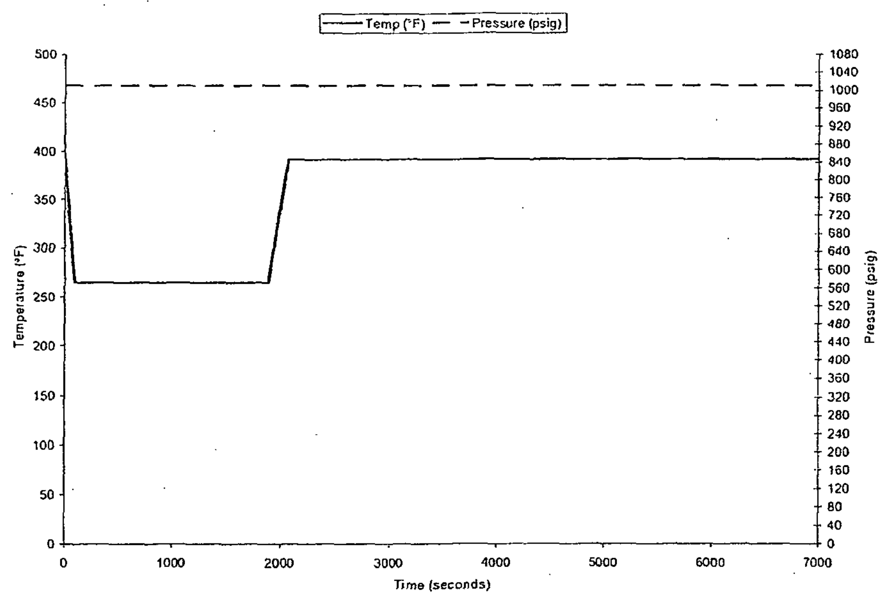


Figure 3-26: Transient 10, Feedwater Bypass

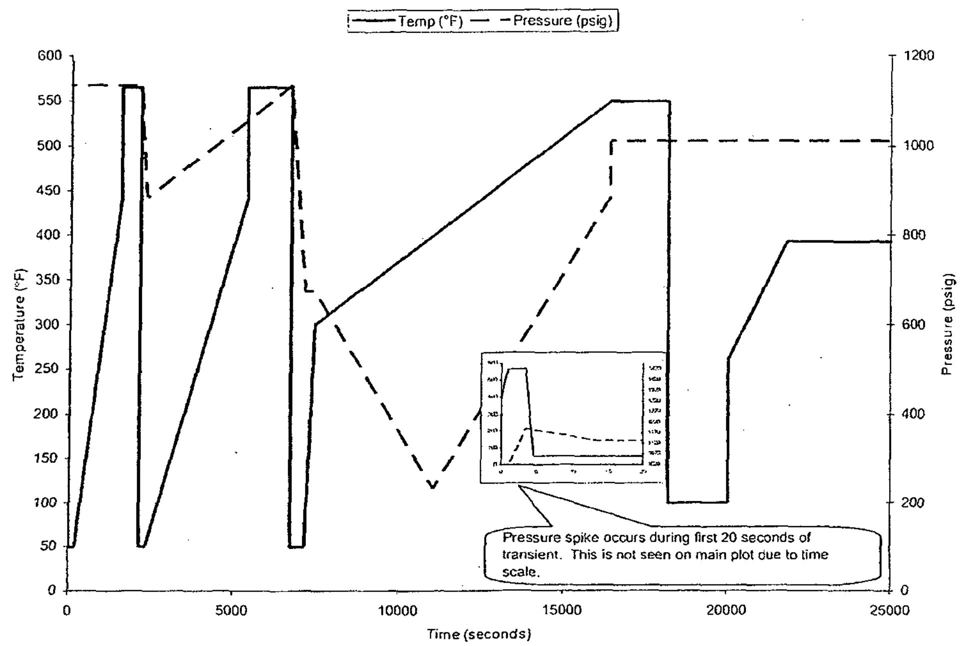


Figure 3-27: Transient 11, Loss of Feedwater Pumps

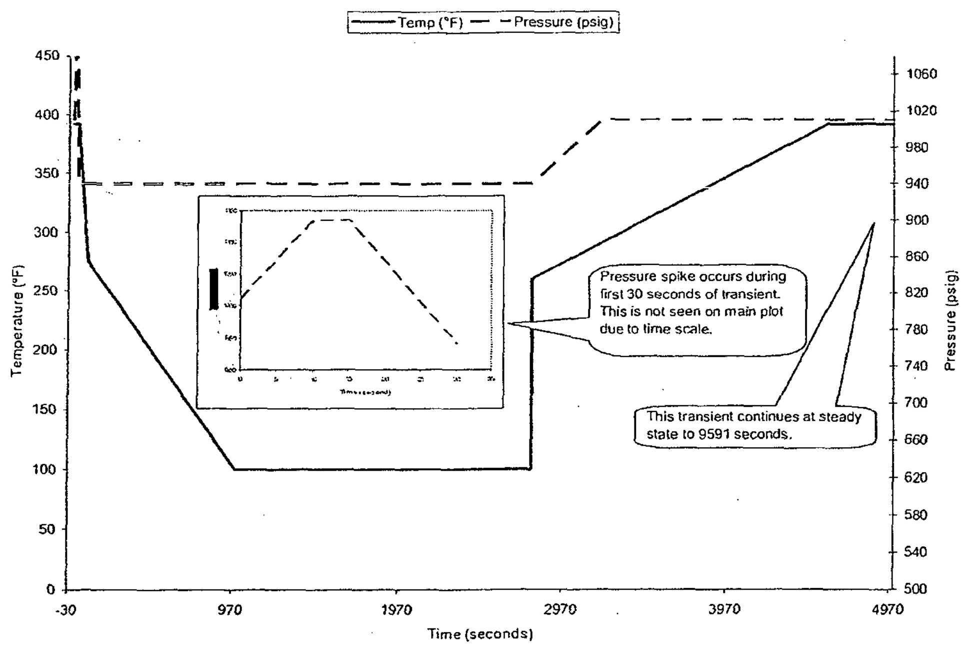


Figure 3-28: Transient 12, Turbine Generator Trip

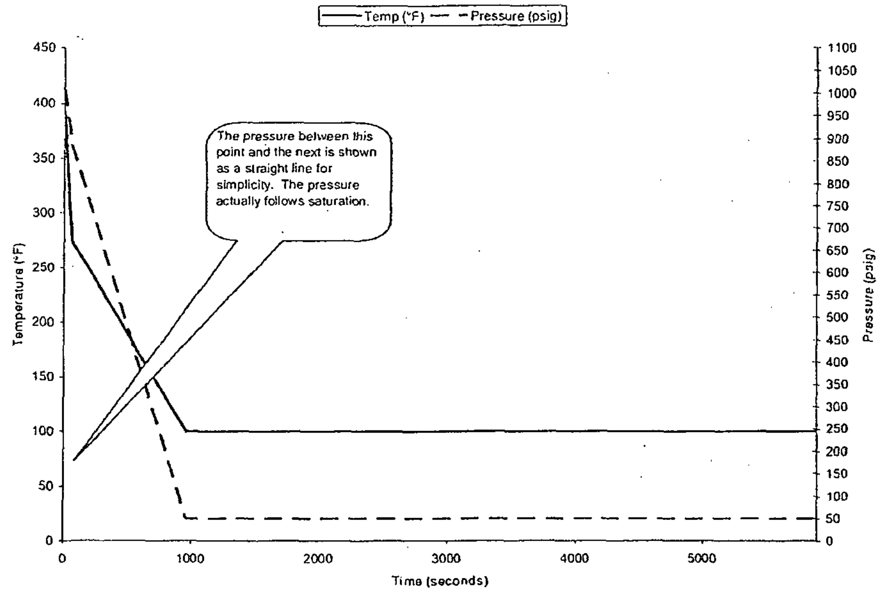


Figure 3-29: Transient 14, SRV Blowdown

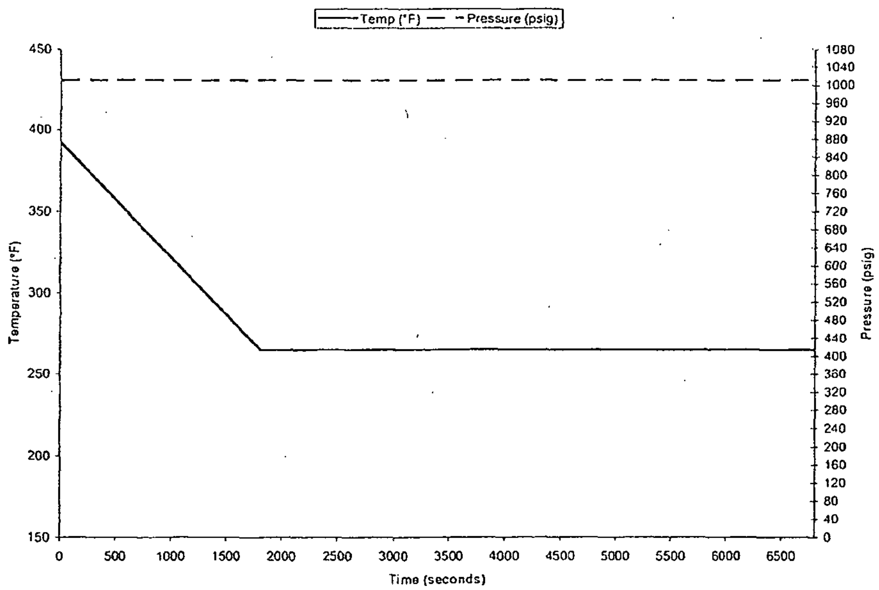


Figure 3-30: Transient 19, Reduction to 0% Power

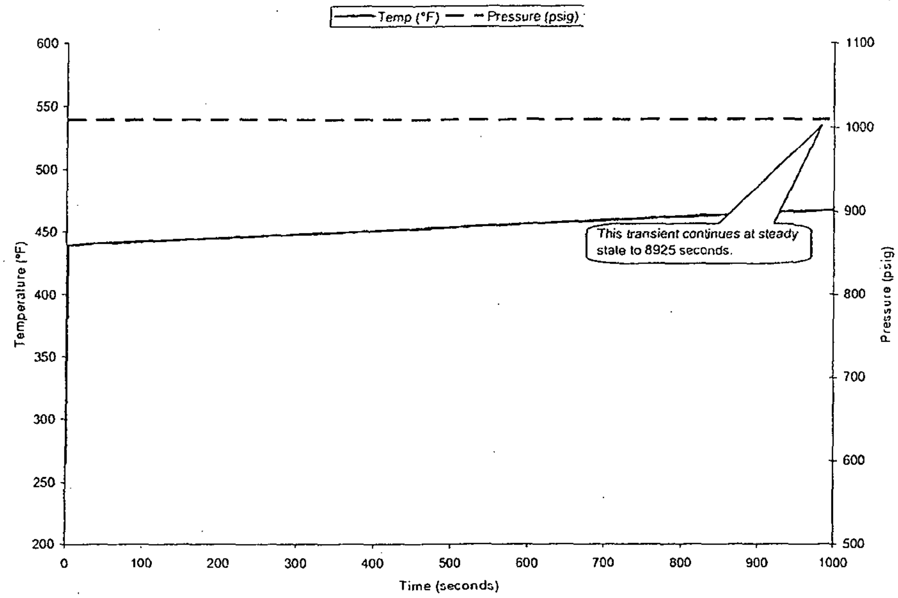


Figure 3-31: Transient 20, Hot Standby (Heatup Portion)

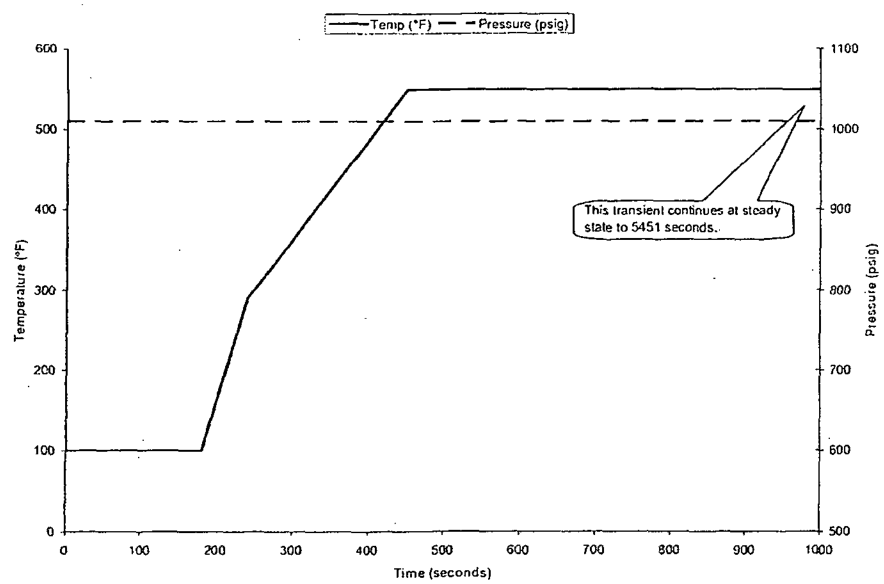


Figure 3-32: Transient 20A, Hot Standby (Feedwater Injection Portion)

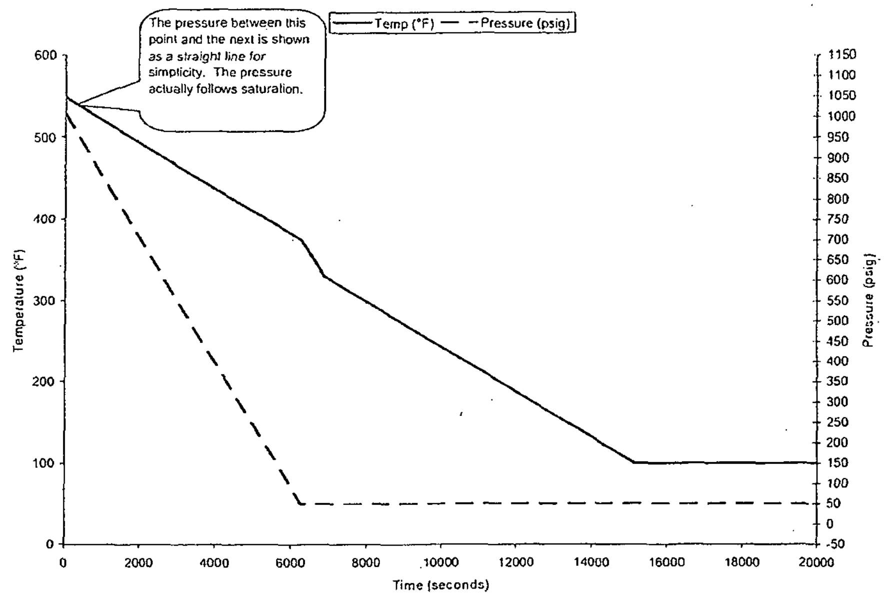


Figure 3-33: Transient 21-23, Shutdown

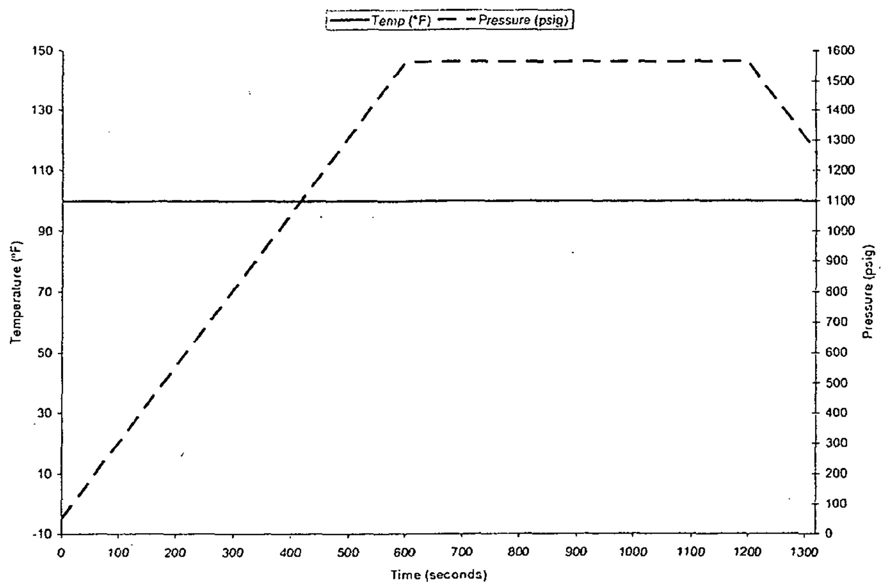


Figure 3-34: Transient 24, Hydrostatic Test

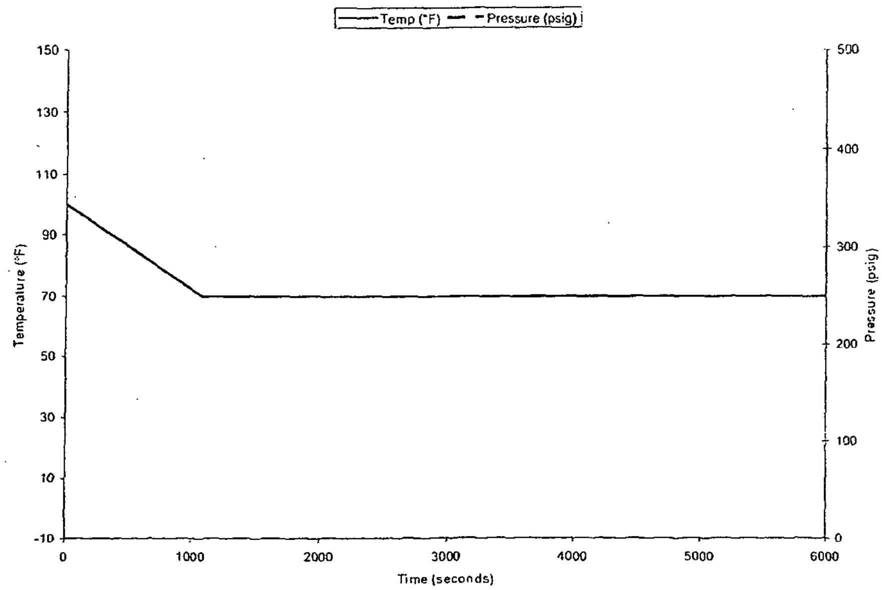


Figure 3-35: Transient 25, Unbolt

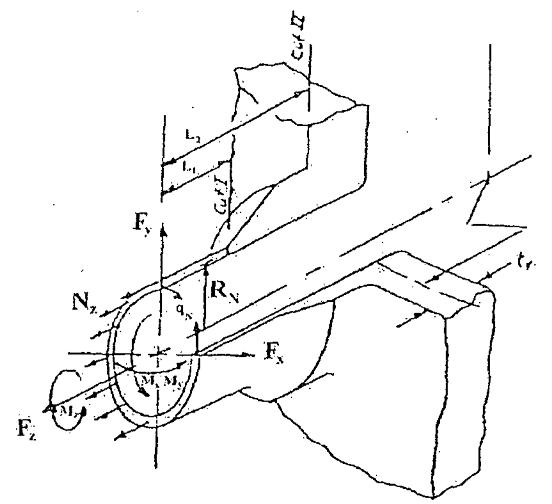


Figure 3-36: External Forces and Moments on the Feedwater Nozzle

4.0 STRESS AND FATIGUE ANALYSIS RESULTS

Fatigue calculations for the VY FW nozzle were performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology (1998 Edition, 2000 Addenda) [15]. Fatigue analysis was performed in the Reference [23] calculation for the two locations identified in Section 3.1.2 using the Green's Functions developed for these two locations and the 60-year projected cycle counts from Reference [19].

Tables 4-1 and 4-2 show the stresses for each location that were used in the fatigue analysis. Columns 2 through 5 of Table 4-1 (for the blend radius) and Table 4-2 (for the safe end) show the final thermal peak and valley output. The pressure values for Column 6 in each table were determined from the transient pressures specified in Tables 3-4 and 3-5. The pressure stress intensities from Section 3.2 were scaled appropriately for each transient case. The scaled piping stress values are shown in Columns 9 and 10 of Tables 4-1 and 4-2. The piping stress intensities from Section 3.3 were scaled based on the transient case RPV fluid temperature and assuming no stress occurs at an ambient temperature of 70°F. Both of these stress intensities were then added to the thermal stress intensity peak and valley points to calculate the final stress values used for the fatigue analysis. In the case of the piping load stress intensities, the sign of the stress intensity was conservatively set to the same sign as the thermal stress intensity to ensure bounding fatigue usage results. Columns 11 and 12 of Tables 4-1 and 4-2 show the summation of all stresses for each thermal peak and valley stress point. The last column shows the number of cycles associated with each peak or valley based on the cycle counts shown in Tables 3-4 and 3-5.

The program FATIGUE.EXE performs the ASME Code peak event-pairing required to calculate a fatigue usage value. The input data for the configuration input file for FATIGUE.EXE, which is named FATIGUE.CFG, is shown in Table 4-3.

The results of the fatigue analysis are presented in Tables 4-4 and 4-5 for the safe end and blend radius for 60 years, respectively. The blend radius cumulative usage factor (CUF) from system cycling is 0.0636 for 60 years. The safe end CUF is 0.1471 for 60 years.

Table 4-1: Feedwater Nozzle Blend Radius Stress Summary

1	2	3	4	5	6	7	8	9	10	11	12	13
Transient Number	Time (s)	Total Stress (psi)	M+B Stress (psi)	Temperature F	Pressure (psig)	Total Pressure Stress (psi)	M+B Pressure Stress (psi)	Total Piping Stress (psi)	M+B Piping Stress (psi)	Total Total Stress (psi)	Total M+B Stress (psi)	Number of Cycles (60 years)
1	0	0	0	70	0	0	0	0	0	0.00	0.00	123
2	0	0	0	70	0	0	0	0	0	0.00	0.00	120
	1680	0	0	100	1100	41506.3	40318.3	15.77042	15.77042	41522.07	40334.07	120
	10880	0	0	100	50	1886.65	1832.65	15.77042	15.77042	1902.42	1848.42	120
3	0	29166	23676	100	50	1886.65	1832.65	15.77042	15.77042	31068.42	25524.42	300
	16782.8	-3577	-3138	549	1010	38110.33	37019.53	-251.801	-251.801	34281.53	33629.73	300
	21164	-3532	-3138	549	1010	38110.33	37019.53	-251.801	-251.801	34326.53	33629.73	300
4	0	-3530	-3158	549	1010	38110.33	37019.53	-251.801	-251.801	34328.53	33609.73	300
	1801.9	29465	22266	244.004	1010	38110.33	37019.53	91.47053	91.47053	67666.80	59377.00	300
	8602	7720	6749	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43937.80	300
5	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	10000
	2229.8	13598	11941	311.002	1010	38110.33	37019.53	126.6901	126.6901	51835.02	49087.22	10000
	8600	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	10000
6	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	2000
	2820.3	15742	13892	280.691	1010	38110.33	37019.53	110.7562	110.7562	53963.09	51022.29	2000
	10400	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	2000
9	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	10
	2524	29006	23417	118.311	1010	38110.33	37019.53	25.39616	25.39616	67141.73	60461.93	10
	10400	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	10
10	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	70
	1632.4	16828	14701	267.399	1010	38110.33	37019.53	103.7688	103.7688	55042.10	51824.30	70
	7070	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	70
11	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	10
	3.5	6620	6632	565	1190	44902.27	43617.07	260.2119	260.2119	51782.48	50509.28	10
	4.5	6190	6608	50	1185	44713.61	43433.81	10.51361	10.51361	50914.12	50052.32	10
	194.5	31720	21067	109.348	1135	42826.96	41601.16	20.68448	20.68448	74567.64	62688.84	10
	2166.3	-4761	-1859	513.483	972	36676.48	35626.72	-233.1304	-233.1304	31682.35	33534.59	10
	2362.5	31268	22070	102.255	1010	38110.33	37019.53	16.95583	16.95583	69395.29	59106.49	10
	6728.3	-4913	-3149	513.448	1010	38110.33	37019.53	-233.112	-233.112	32964.22	33637.42	10
	7149.9	32114	21472	83.333	1010	38110.33	37019.53	7.0089	7.0089	70231.34	58498.54	10
	18213.3	-3565	-3162	503.978	1010	38110.33	37019.53	-228.1338	-228.1338	34317.20	33629.40	10
	19122.6	29156	23083	100.048	1010	38110.33	37019.53	15.79565	15.79565	67282.13	60118.33	10
	26814.5	7720	6410	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43598.80	10
12	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	60
	10	7720	6752	392	1135	42826.96	41601.16	169.2692	169.2692	50716.22	48522.42	60
	30	7720	6752	392	940	35469.02	34453.82	169.2692	169.2692	43358.29	41375.09	60
	2033.7	28648	25301	132.007	940	35469.02	34453.82	32.59588	32.59588	64149.62	59787.42	60
	9591	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	60
13	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	1
	10	7720	6752	392	1375	51882.88	50397.88	169.2692	169.2692	59772.14	57319.14	1
	30	7720	6752	392	940	35469.02	34453.82	169.2692	169.2692	43358.29	41375.09	1
	2033.7	28648	25301	132.007	1010	38110.33	37019.53	32.59588	32.59588	66790.93	62353.13	1
	9591	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	1
14	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	1
	5960	28487	25650	100	50	1886.65	1832.65	15.77042	15.77042	30389.42	27498.42	1
15	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	228
	10	7720	6752	392	1135	42826.96	41601.16	169.2692	169.2692	50716.22	48522.42	228
	30	7720	6752	392	940	35469.02	34453.82	169.2692	169.2692	43358.29	41375.09	228
	2033.7	28648	25301	132.007	1010	38110.33	37019.53	32.59588	32.59588	66790.93	62353.13	228
	9591	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	228
19	0	7720	6752	392	1010	38110.33	37019.53	169.2692	169.2692	45999.60	43940.80	300
	6800	16752	14971	265	1010	38110.33	37019.53	102.5077	102.5077	54964.84	52093.04	300
20	0	17151	13815	265	1010	38110.33	37019.53	102.5077	102.5077	55363.84	50937.04	300
	8925	-3531	-3146	549	1010	38110.33	37019.53	-251.801	-251.801	34327.53	33621.73	300
20A	0	-3530	-3158	549	1010	38110.33	37019.53	-251.801	-251.801	34328.53	33609.73	300
	183	28102	12153	233	1010	38110.33	37019.53	85.68595	85.68595	66298.02	49258.22	300
	5451	-3530	-3158	549	1010	38110.33	37019.53	-251.801	-251.801	34328.53	33609.73	300
21-23	0	-3530	-3158	549	1010	38110.33	37019.53	-251.801	-251.801	34328.53	33609.73	300
	20144	29168	23656	100	50	1886.65	1832.65	15.77042	15.77042	31070.42	25504.42	300
24	0	0	0	100	50	1886.65	1832.65	15.77042	15.77042	1902.42	1848.42	1
	600	0	0	100	1563	58976.68	57288.64	15.77042	15.77042	58992.45	57304.41	1
	2400	0	0	100	50	1886.65	1832.65	15.77042	15.77042	1902.42	1848.42	1
25	0	0	0	100	0	0	0	15.77042	15.77042	15.77	15.77	123
	1580	0	0	70	0	0	0	0	0	0.00	0.00	123

For notes, see last page of table…

Table 4-1: Feedwater Nozzle Blend Radius Stress Summary (continued)

NOTES:
- Column 1: Transient number identification.
- Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
- Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
- Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
- Column 5: Temperature per total stress intensity.
- Column 6: Pressure per Table 3-4.
- Column 7: Total pressure stress intensity from the quantity (Column 6 x 37733)/1000 [Table3, 10].
- Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 36653)/1000 [Table 3, 10].
- Column 9: Total external stress from calculation in Table 3-2, 265.47 psi*(Column 5-70°F)/(575°F -70°F).
- Column 10: Same as Column 9, but for M+B stress.
- Column 11: Sum of total stresses (Columns 3, 7, and 9).
- Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
- Column 13: Number of cycles for the transient (60 years).

Table 4-2: Feedwater Nozzle Safe End Stress Summary

1	2	3	4	5	6	7	8	9	10	11	12	13
Transient Number	Time (s)	Total Stress (psi)	M+B Stress (psi)	Temperature F	Pressure (psig)	Total Pressure Stress (psi)	M+B Pressure Stress (psi)	Total Piping Stress (psi)	M+B Piping Stress (psi)	Total Total Stress (psi)	Total M+B Stress (psi)	Number of Cycles (60 years)
1	0	0	0	70	0	0	0	0	0	0.00	0.00	123
2	0	0	0	70	0	0	0	0	0	0.00	0.00	120
	1680	0	0	100	1100	9780.1	9562.3	339.0875	339.0875	10119.19	9901.39	120
	6960	0	0	100	50	444.55	434.65	339.0875	339.0875	783.64	773.74	120
3	0	-170	-165	100	50	444.55	434.65	-339.0875	-339.0875	-64.54	-69.44	300
	153.2	-235	-212	104.256	50	444.55	434.65	-387.1927	-387.1927	-177.64	-164.54	300
	16328.2	2	3	549	1010	8979.91	8779.93	5414.097	5414.097	14396.01	14197.03	300
	16664	-1	0	549	1010	8979.91	8779.93	-5414.097	5414.097	3564.81	14194.03	300
4	0	-3	-2	549	1010	8979.91	8779.93	-5414.097	-5414.097	3562.81	3363.83	300
	3.6	44060	30988	100	1010	8979.91	8779.93	339.0875	339.0875	53379.00	40107.02	300
	1804.6	-15889	-11224	260.286	1010	8979.91	8779.93	-2150.787	-2150.787	-9059.88	-4594.86	300
	4102	21	23	392	1010	8979.91	8779.93	3639.539	3639.539	12640.45	12442.47	300
5	0	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	10000
	900.1	244	189	310	1010	8979.91	8779.93	2712.7	2712.7	11936.61	11681.63	10000
	3600	-169	-110	392	1010	8979.91	8779.93	-3639.539	-3639.539	5171.37	5030.39	10000
	3684.4	33	35	392	1010	8979.91	8779.93	3639.539	3639.539	12652.45	12454.47	10000
	4100	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	10000
6	0	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	2000
	1800.1	196	159	280	1010	8979.91	8779.93	2373.612	2373.612	11549.52	11312.54	2000
	5400.2	-108	-68	392	1010	8979.91	8779.93	-3639.539	-3639.539	5232.37	5072.39	2000
	5496.6	29	31	392	1010	8979.91	8779.93	3639.539	3639.539	12648.45	12450.47	2000
	5900	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	2000
9	0	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	10
	97.3	180	137	385.135	1010	8979.91	8779.93	3561.945	3561.945	12721.85	12478.87	10
	1884.1	63	65	265	1010	8979.91	8779.93	2204.069	2204.069	11246.98	11049.00	10
	2059.2	1161	859	226.597	1010	8979.91	8779.93	1770.003	1770.003	11910.91	11408.93	10
	3420.1	-334	-211	265	1010	8979.91	8779.93	-2204.069	-2204.069	6441.84	6364.86	10
	3490.2	97	98	265	1010	8979.91	8779.93	2204.069	2204.069	11280.98	11082.00	10
	5400.1	-126	-80	392	1010	8979.91	8779.93	-3639.539	-3639.539	5214.37	5060.39	10
	5470.6	31	32	392	1010	8979.91	8779.93	3639.539	3639.539	12650.45	12451.47	10
	5900	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	10
10	0	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	70
	77.1	2308	3188	285.461	1010	8979.91	8779.93	2435.338	2435.338	13723.25	14403.27	70
	169.4	-12	-13	265	1010	8979.91	8779.93	-2204.069	-2204.069	6763.84	6562.86	70
	1890	74	72	265	1010	8979.91	8779.93	2204.069	2204.069	11257.98	11056.00	70
	1968.2	-1069	-1511	322.362	1010	8979.91	8779.93	-2852.427	-2852.427	5058.48	4416.50	70
	2147.2	91	90	392	1010	8979.91	8779.93	3639.539	3639.539	12710.45	12509.47	70
	2570	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	70
11	0	-29	-27	392	1010	8979.91	8779.93	-3639.539	-3639.539	5311.37	5113.39	10
	2.9	-20317	-13859	565	1147	10197.98	9970.871	-5594.944	-5594.944	-15713.97	-9483.07	10
	6.8	42852	29563	565	1172	10420.25	10188.2	5594.944	5594.944	58867.20	45346.14	10
	1567.4	-15216	-10526	565	1135	10091.29	9866.555	-5594.944	-5594.944	-10719.66	-6254.39	10
	2168.4	60377	41773	50	1134	10082.39	9857.862	-226.0583	-226.0583	70233.34	51404.80	10
	5409.4	-14924	-10329	565	1054	9371.114	9162.422	-5594.944	-5594.944	-11147.83	-6761.52	10
	6730.4	60377	41773	50	1133	10073.5	9849.169	-226.0583	-226.0583	70224.44	51396.11	10
	7243.2	-1965	-1434	128.917	675	6001.425	5867.775	-665.9339	-665.9339	3370.49	3767.84	10
	18215.4	52636	36417	100	1010	8979.91	8779.93	339.0875	339.0875	61955.00	45536.02	10
	20015.5	-24511	-16189	260.183	1010	8979.91	8779.93	-2149.623	-2149.623	-17680.71	-9558.69	10
	22314.5	22	23	392	937	8330.867	8145.341	3639.539	3639.539	11992.41	11807.88	10
12	0	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	60
	10	23	22	392	1135	10091.29	9866.555	3639.539	3639.539	13753.82	13528.09	60
	30	23	22	392	940	8357.54	8171.42	3639.539	3639.539	12020.08	11832.96	60
	90	3174	4383	275	940	8357.54	8171.42	2317.098	2317.098	13848.64	14871.52	60
	2793.5	-16189	-24511	260.183	941	8366.431	8180.113	-2149.623	-2149.623	-9972.19	-18480.51	60
	5091	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	60
13	0	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	1
	10	23	22	392	1375	12225.13	11952.88	3639.539	3639.539	15887.66	15614.41	1
	30	23	22	392	940	8357.54	8171.42	3639.539	3639.539	12020.08	11832.96	1
	90	3174	4383	275	940	8357.54	8171.42	2317.098	2317.098	13848.64	14871.52	1
	2793.5	-16189	-24511	260.183	941	8366.431	8180.113	-2149.623	-2149.623	-9972.19	-18480.51	1
	5091	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	1

For notes, see last page of table...

Table 4-2: Feedwater Nozzle Safe End Stress Summary (continued)

1	2	3	4	5	6	7	8	9	10	11	12	13
Transient Number	Time (s)	Total Stress (psi)	M+B Stress (psi)	Temperature F	Pressure (psig)	Total Pressure Stress (psi)	M+B Pressure Stress (psi)	Total Piping Stress (psi)	M+B Piping Stress (psi)	Total Total Stress (psi)	Total M+B Stress (psi)	Number of Cycles (60 years)
14	0	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	1
	60	4383	3174	275	885	7868.535	7693.305	2317.098	2317.098	14568.63	13184.40	1
	148	420	300	258.492	803	7139.473	6980.479	2130.509	2130.509	9689.98	9410.99	1
	960	544	424	100	50	444.55	434.65	339.0875	339.0875	1327.64	1197.74	1
	1460	137	139	100	50	444.55	434.65	339.0875	339.0875	920.64	912.74	1
15	0	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	228
	10	23	22	392	1135	10091.29	9866.555	3639.539	3639.539	13753.82	13528.09	228
	30	23	22	392	940	8357.54	8171.42	3639.539	3639.539	12020.08	11832.96	228
	90	3174	4383	275	940	8357.54	8171.42	2317.098	2317.098	13848.64	14871.52	228
	2793.5	-16189	-24511	260.183	941	8366.431	8180.113	-2149.623	-2149.623	-9972.19	-18480.51	228
	5091	23	22	392	1010	8979.91	8779.93	3639.539	3639.539	12642.45	12441.47	228
19	0	22	23	392	1010	8979.91	8779.93	3639.539	3639.539	12641.45	12442.47	300
	1800	219	177	265	1010	8979.91	8779.93	2204.069	2204.069	11402.98	11161.00	300
	2300	72	74	265	1010	8979.91	8779.93	2204.069	2204.069	11255.98	11058.00	300
20	0	-109	-105	265	1010	8979.91	8779.93	-2204.069	-2204.069	6666.84	6470.86	300
	4	-17288	-12189	440.106	1010	8979.91	8779.93	-4183.277	-4183.277	-12491.37	-7592.35	300
	4425	-2	-1	549	1010	8979.91	8779.93	-5414.097	-5414.097	3563.81	3364.83	300
20A	0	-3	-2	549	1010	8979.91	8779.93	-5414.097	-5414.097	3562.81	3363.83	300
	4	44060	30988	100	1010	8979.91	8779.93	339.0875	339.0875	53379.00	40107.02	300
	241	-7461	-5525	290.247	1010	8979.91	8779.93	-2489.433	-2489.433	-970.52	765.50	300
	572	128	132	549	1010	8979.91	8779.93	5414.097	5414.097	14522.01	14326.03	300
	951	-3	-2	549	1010	8979.91	8779.93	-5414.097	-5414.097	3562.81	3363.83	300
21-23	0	-3	-2	549	1010	8979.91	8779.93	-5414.097	-5414.097	3562.81	3363.83	300
	138	62	45	545.167	989	8793.199	8597.377	5370.773	5370.773	14225.97	14013.15	300
	6264	-5	-20	374.97	50	444.55	434.65	-3447.05	-3447.05	-3007.50	-3032.40	300
	6390	104	59	366.172	50	444.55	434.65	3347.607	3347.607	3896.16	3841.26	300
	15644	-173	-167	100	50	444.55	434.65	-339.0875	-339.0875	-67.54	-71.44	300
24	0	0	0	100	50	444.55	434.65	339.0875	339.0875	783.64	773.74	1
	600	0	0	100	1563	13896.63	13587.16	339.0875	339.0875	14235.72	13926.25	1
	2400	0	0	100	50	444.55	434.65	339.0875	339.0875	783.64	773.74	1
25	0	0	0	100	0	0	0	339.0875	339.0875	339.09	339.09	123
	1580	0	0	70	0	0	0	0	0	0.00	0.00	123

NOTES: Column 1: Transient number identification.
Column 2: Time during transient where a maxima or minima stress intensity occurs from P-V.OUT output file.
Column 3: Maxima or minima total stress intensity from P-V.OUT output file.
Column 4: Maxima or minima membrane plus bending stress intensity from P-V.OUT output file.
Column 5: Temperature per total stress intensity.
Column 6: Pressure per Table 3-5.
Column 7: Total pressure stress intensity from the quantity (Column 6 x 8891)/1000 [Table 3, 10].
Column 8: Membrane plus bending pressure stress intensity from the quantity (Column 6 x 8693)/1000 [Table3, 10].
Column 9: Total external stress from calculation in Table 3-2, 5707.97 psi*(Column 5-70°F)/(575°F -70°F).
Column 10: Same as Column 9, but for M+B stress.
Column 11: Sum of total stresses (Columns 3, 7, and 9).
Column 12: Sum of membrane plus bending stresses (Columns 4, 8, and 10).
Column 13: Number of cycles for the transient (60 years).

Table 4-3: Fatigue Parameters Used in the Feedwater Nozzle Fatigue Analysis

	Blend Radius	Safe End
Parameters *m* and *n* for Computing K_e	2.0 & 0.2 (low alloy steel) [15]	3.0 & 0.2 (carbon steel) [15]
Design Stress Intensity Values, S_m	26700 psi [9] @ 600°F	17800 psi [9] @ 600°F
Elastic Modulus from Applicable Fatigue Curve	30.0×10^6 psi [15]	30.0×10^6 psi [15]
Elastic Modulus Used in Finite Element Model	26.7×10^6 psi [10]	28.1×10^6 psi [10]
The Geometric Stress Concentration Factor K_t	1.0	1.34 [2, page 35 of S4]

Table 4-4: Fatigue Results for Feedwater Nozzle Blend Radius

```
LOCATION = LOCATION NO. 2 -- BLEND RADIUS
FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
m = 2.0
n =  .2
Sm = 26700. psi
Ecurve = 3.000E+07 psi
Eanalysis = 2.670E+07 psi
Kt = 1.00
```

MAX	MIN	RANGE	MEM+BEND	Ke	Salt	Napplied	Nallowed	U
74568.	0.	74568.	62689.	1.000	41892.	1.000E+01	7.488E+03	.0013
70231.	0.	70231.	58499.	1.000	39456.	1.000E+01	8.944E+03	.0011
69395.	0.	69395.	59106.	1.000	38986.	1.000E+01	9.268E+03	.0011
67667.	0.	67667.	59377.	1.000	38015.	9.300E+01	9.988E+03	.0093
67667.	0.	67667.	59377.	1.000	38015.	1.200E+02	9.988E+03	.0120
67667.	0.	67667.	59377.	1.000	38015.	8.700E+01	9.988E+03	.0087
67282.	0.	67282.	60118.	1.000	37799.	1.000E+01	1.018E+04	.0010
67142.	0.	67142.	60462.	1.000	37720.	1.000E+01	1.025E+04	.0010
66791.	0.	66791.	62353.	1.000	37523.	1.000E+00	1.044E+04	.0001
66791.	0.	66791.	62353.	1.000	37523.	1.500E+01	1.044E+04	.0014
66791.	16.	66775.	62337.	1.000	37514.	1.230E+02	1.045E+04	.0118
66791.	1902.	64889.	60505.	1.000	36454.	9.000E+01	1.152E+04	.0078
66298.	1902.	64396.	47410.	1.000	36177.	3.000E+01	1.182E+04	.0025
66298.	1902.	64396.	47410.	1.000	36177.	1.000E+00	1.182E+04	.0001
66298.	1902.	64396.	47410.	1.000	36177.	1.000E+00	1.182E+04	.0001
66298.	30389.	35909.	21760.	1.000	20173.	1.000E+00	9.581E+04	.0000
66298.	31068.	35230.	23734.	1.000	19792.	2.670E+02	1.038E+05	.0026
64150.	31068.	33081.	34263.	1.000	18585.	3.300E+01	1.303E+05	.0003
64150.	31070.	33079.	34283.	1.000	18584.	2.700E+01	1.303E+05	.0002
59772.	31070.	28702.	31815.	1.000	16125.	1.000E+00	2.222E+05	.0000
58992.	31070.	27922.	31800.	1.000	15687.	1.000E+00	2.519E+05	.0000
55364.	31070.	24293.	25433.	1.000	13648.	2.710E+02	4.757E+05	.0006
55364.	31682.	23681.	17402.	1.000	13304.	1.000E+01	5.703E+05	.0000
55364.	32964.	22400.	17300.	1.000	12584.	1.000E+01	9.414E+05	.0000
55364.	34282.	21082.	17307.	1.000	11844.	9.000E+00	1.912E+06	.0000
55042.	34282.	20761.	18195.	1.000	11663.	7.000E+01	2.231E+06	.0000
54965.	34282.	20683.	18463.	1.000	11620.	2.210E+02	2.310E+06	.0001
54965.	34317.	20648.	18464.	1.000	11600.	1.000E+01	2.348E+06	.0000
54965.	34327.	20638.	18463.	1.000	11595.	6.900E+01	2.358E+06	.0000
53963.	34327.	19637.	17393.	1.000	11032.	2.310E+02	3.757E+06	.0001
53963.	34328.	19636.	17401.	1.000	11031.	3.000E+02	3.758E+06	.0001
53963.	34329.	19635.	17413.	1.000	11031.	3.000E+02	3.760E+06	.0001
53963.	34329.	19635.	17413.	1.000	11031.	3.000E+02	3.760E+06	.0001
53963.	34329.	19635.	17413.	1.000	11031.	3.000E+02	3.760E+06	.0001
53963.	34329.	19635.	17413.	1.000	11031.	3.000E+02	3.760E+06	.0001
53963.	41522.	12441.	10688.	1.000	6989.	1.200E+02	1.000E+20	.0000
53963.	43358.	10605.	9647.	1.000	5958.	6.000E+01	1.000E+20	.0000
53963.	43358.	10605.	9647.	1.000	5958.	1.000E+00	1.000E+20	.0000
53963.	43358.	10605.	9647.	1.000	5958.	8.800E+01	1.000E+20	.0000
51835.	43358.	8477.	7712.	1.000	4762.	1.400E+02	1.000E+20	.0000
51835.	46000.	5835.	5149.	1.000	3278.	3.000E+02	1.000E+20	.0000

51835.	46000.	5835.	5146.	1.000	3278.	9.560E+03	1.000E+20	.0000
51782.	46000.	5783.	6568.	1.000	3249.	1.000E+01	1.000E+20	.0000
50914.	46000.	4915.	6112.	1.000	2761.	1.000E+01	1.000E+20	.0000
50716.	46000.	4717.	4582.	1.000	2650.	6.000E+01	1.000E+20	.0000
50716.	46000.	4717.	4582.	1.000	2650.	2.280E+02	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	1.320E+02	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	1.000E+04	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	2.000E+03	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	2.000E+03	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	1.000E+01	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	1.000E+01	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	7.000E+01	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	7.000E+01	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	1.000E+01	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	1.000E+01	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	6.000E+01	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	6.000E+01	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	1.000E+00	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	1.000E+00	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	1.000E+00	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	2.280E+02	1.000E+20	.0000
46000.	46000.	0.	0.	1.000	0.	2.280E+02	1.000E+20	.0000
								=======
						TOTAL USAGE FACTOR =		.0636

Table 4-5: Fatigue Results for the Feedwater Nozzle Safe End

LOCATION = LOCATION NO. 1 -- SAFE END
FATIGUE CURVE = 1 (1 = CARBON/LOW ALLOY, 2 = STAINLESS STEEL)
m = 3.0
n = .2
Sm = 17800. psi
Ecurve = 3.000E+07 psi
Eanalysis = 2.810E+07 psi
Kt = 1.34

MAX	MIN	RANGE	MEM+BEND	Ke	Salt	Napplied	Nallowed	U
70233.	-17681.	87914.	60963.	1.283	74422.	1.000E+01	1.338E+03	.0075
70224.	-15714.	85938.	60879.	1.280	72869.	1.000E+01	1.415E+03	.0071
61955.	-12491.	74446.	53128.	1.000	49383.	1.000E+01	4.568E+03	.0022
58867.	-12491.	71359.	52938.	1.000	47700.	1.000E+01	5.094E+03	.0020
53379.	-12491.	65870.	47699.	1.000	43819.	2.800E+02	6.552E+03	.0427
53379.	-11148.	64527.	46869.	1.000	42951.	1.000E+01	6.953E+03	.0014
53379.	-10720.	64099.	46361.	1.000	42631.	1.000E+01	7.109E+03	.0014
53379.	-9972.	63351.	58588.	1.194	53087.	6.000E+01	3.628E+03	.0165
53379.	-9972.	63351.	58588.	1.194	53087.	1.000E+00	3.628E+03	.0003
53379.	-9972.	63351.	58588.	1.194	53087.	2.280E+02	3.628E+03	.0628
53379.	-9060.	62439.	44702.	1.000	41444.	1.100E+01	7.731E+03	.0014
15888.	-9060.	24948.	20209.	1.000	16985.	1.000E+00	1.802E+05	.0000
14569.	-9060.	23629.	17779.	1.000	15840.	1.000E+00	2.410E+05	.0000
14522.	-9060.	23582.	18921.	1.000	16022.	2.870E+02	2.287E+05	.0013
14522.	-3008.	17530.	17358.	1.000	12508.	1.300E+01	9.944E+05	.0000
14396.	-3008.	17404.	17229.	1.000	12417.	2.870E+02	1.083E+06	.0003
14396.	-971.	15367.	13432.	1.000	10641.	1.300E+01	5.165E+06	.0000
14236.	-971.	15206.	13161.	1.000	10506.	1.000E+00	5.563E+06	.0000
14226.	-971.	15196.	13248.	1.000	10516.	2.860E+02	5.531E+06	.0001
14226.	-178.	14404.	14178.	1.000	10262.	1.400E+01	6.379E+06	.0000
13849.	-178.	14026.	15036.	1.000	10216.	6.000E+01	6.547E+06	.0000
13849.	-178.	14026.	15036.	1.000	10216.	1.000E+00	6.547E+06	.0000
13849.	-178.	14026.	15036.	1.000	10216.	2.250E+02	6.547E+06	.0000
13849.	-68.	13916.	14943.	1.000	10141.	3.000E+00	6.837E+06	.0000
13754.	-68.	13821.	13600.	1.000	9846.	6.000E+01	8.117E+06	.0000
13754.	-68.	13821.	13600.	1.000	9846.	2.280E+02	8.117E+06	.0000
13723.	-68.	13791.	14475.	1.000	9989.	9.000E+00	7.465E+06	.0000
13723.	-65.	13788.	14473.	1.000	9987.	6.100E+01	7.474E+06	.0000
12722.	-65.	12786.	12548.	1.000	9103.	1.000E+01	1.729E+07	.0000
12710.	-65.	12775.	12579.	1.000	9102.	7.000E+01	1.730E+07	.0000
12652.	-65.	12717.	12524.	1.000	9061.	1.590E+02	1.833E+07	.0000
12652.	0.	12652.	12454.	1.000	9014.	1.230E+02	1.959E+07	.0000
12652.	0.	12652.	12454.	1.000	9014.	1.200E+02	1.959E+07	.0000
12652.	0.	12652.	12454.	1.000	9014.	1.230E+02	1.959E+07	.0000
12652.	339.	12313.	12115.	1.000	8772.	1.230E+02	2.905E+07	.0000
12652.	784.	11869.	11681.	1.000	8456.	1.200E+02	4.952E+07	.0000
12652.	784.	11869.	11681.	1.000	8456.	1.000E+00	4.952E+07	.0000
12652.	784.	11869.	11681.	1.000	8456.	1.000E+00	4.952E+07	.0000
12652.	921.	11732.	11542.	1.000	8357.	1.000E+00	5.462E+07	.0000
12652.	1328.	11325.	11257.	1.000	8088.	1.000E+00	7.100E+07	.0000
12652.	3370.	9282.	8687.	1.000	6531.	1.000E+01	1.000E+20	.0000
12652.	3563.	9090.	9091.	1.000	6502.	3.000E+02	1.000E+20	.0000

12652.	3563.	9090.	9091.	1.000	6502.	3.000E+02	1.000E+20	.0000
12652.	3563.	9090.	9091.	1.000	6502.	3.000E+02	1.000E+20	.0000
12652.	3563.	9090.	9091.	1.000	6502.	3.000E+02	1.000E+20	.0000
12652.	3564.	9089.	9090.	1.000	6501.	3.000E+02	1.000E+20	.0000
12652.	3565.	9088.	-1740.	1.000	4535.	3.000E+02	1.000E+20	.0000
12652.	3896.	8756.	8613.	1.000	6237.	3.000E+02	1.000E+20	.0000
12652.	5058.	7594.	8038.	1.000	5513.	7.000E+01	1.000E+20	.0000
12652.	5171.	7481.	7424.	1.000	5341.	7.048E+03	1.000E+20	.0000
12650.	5171.	7479.	7421.	1.000	5339.	1.000E+01	1.000E+20	.0000
12648.	5171.	7477.	7420.	1.000	5338.	2.000E+03	1.000E+20	.0000
12642.	5171.	7471.	7411.	1.000	5333.	7.000E+01	1.000E+20	.0000
12642.	5171.	7471.	7411.	1.000	5333.	7.000E+01	1.000E+20	.0000
12642.	5171.	7471.	7411.	1.000	5333.	6.000E+01	1.000E+20	.0000
12642.	5171.	7471.	7411.	1.000	5333.	6.000E+01	1.000E+20	.0000
12642.	5171.	7471.	7411.	1.000	5333.	1.000E+00	1.000E+20	.0000
12642.	5171.	7471.	7411.	1.000	5333.	1.000E+00	1.000E+20	.0000
12642.	5171.	7471.	7411.	1.000	5333.	2.280E+02	1.000E+20	.0000
12642.	5171.	7471.	7411.	1.000	5333.	2.280E+02	1.000E+20	.0000
12641.	5171.	7470.	7412.	1.000	5333.	2.240E+02	1.000E+20	.0000
12641.	5214.	7427.	7382.	1.000	5304.	1.000E+01	1.000E+20	.0000
12641.	5232.	7409.	7370.	1.000	5293.	2.000E+03	1.000E+20	.0000
12641.	5311.	7330.	7329.	1.000	5243.	1.000E+01	1.000E+20	.0000
12641.	6442.	6200.	6078.	1.000	4412.	1.000E+01	1.000E+20	.0000
12641.	6667.	5975.	5972.	1.000	4273.	3.000E+02	1.000E+20	.0000
12641.	6764.	5878.	5880.	1.000	4205.	7.000E+01	1.000E+20	.0000
12641.	9690.	2951.	3031.	1.000	2126.	1.000E+00	1.000E+20	.0000
12641.	10119.	2522.	2541.	1.000	1808.	1.200E+02	1.000E+20	.0000
12641.	11247.	1394.	1393.	1.000	997.	1.000E+01	1.000E+20	.0000
12641.	11256.	1385.	1384.	1.000	991.	3.000E+02	1.000E+20	.0000
12641.	11258.	1383.	1386.	1.000	990.	7.000E+01	1.000E+20	.0000
12641.	11281.	1360.	1360.	1.000	973.	1.000E+01	1.000E+20	.0000
12641.	11403.	1238.	1281.	1.000	894.	3.000E+02	1.000E+20	.0000
12641.	11550.	1092.	1130.	1.000	788.	2.000E+03	1.000E+20	.0000
12641.	11911.	731.	1034.	1.000	578.	1.000E+01	1.000E+20	.0000
12641.	11937.	705.	761.	1.000	514.	4.555E+03	1.000E+20	.0000
12641.	11937.	705.	761.	1.000	514.	5.445E+03	1.000E+20	.0000
12641.	11992.	649.	635.	1.000	462.	1.000E+01	1.000E+20	.0000
12641.	12020.	621.	610.	1.000	442.	6.000E+01	1.000E+20	.0000
12641.	12020.	621.	610.	1.000	442.	1.000E+00	1.000E+20	.0000
12641.	12020.	621.	610.	1.000	442.	2.280E+02	1.000E+20	.0000
12641.	12640.	1.	0.	1.000	1.	3.000E+02	1.000E+20	.0000
12641.	12641.	0.	0.	1.000	0.	3.956E+03	1.000E+20	.0000
12641.	12641.	0.	0.	1.000	0.	2.000E+03	1.000E+20	.0000
12641.	12641.	0.	0.	1.000	0.	2.000E+03	1.000E+20	.0000
12641.	12641.	0.	0.	1.000	0.	1.000E+01	1.000E+20	.0000
12641.	12641.	0.	0.	1.000	0.	1.000E+01	1.000E+20	.0000
12641.	12641.	0.	0.	1.000	0.	1.000E+00	1.000E+20	.0000
								=======
							TOTAL USAGE FACTOR =	.1471

5.0 ENVIRONMENTAL FATIGUE ANALYSIS

In the response to NRC request for additional information (RAI) 4.3-H-02 [19], VYNPS states that they have conservatively assumed that fatigue cracks may be present in the clad. VYNPS manages this cracking by performing periodic inspections that were implemented in response to Generic Letters 80-095 and 81-11, and NUREG-0619. The inspection frequency is based on the calculated fatigue crack growth of a postulated flaw in the nozzle inner blend radius. The VYNPS fatigue crack growth calculation uses methods in compliance with GE BWR Owners Group Topical Report "Alternate BWR Feedwater Nozzle Inspection Requirements", GE-NE-523-A71-0594, Revision 1, August 1999 and the associated NRC Final Safety Evaluation (TAC No. MA6787) dated March 10, 2000. The NRC has reviewed and approved this approach to handling FW nozzle inner blend radius cracking (Letter D.H. Dorman (USNRC) to D.A. Reid (VYNPC), Subject: Evaluation of Request for Relief from NUREG-0619 for VYNPS dated 2/6/95, (TAC No. M88803)).

The analysis performed for the feedwater nozzle calculated fatigue in the blend radius base metal, not the clad. This is consistent with the VYNPS position stated in the response to RAI 4.3-H-02, and is also consistent with ASME Code methodology since cladding is structurally neglected in fatigue analyses, per ASME Code, Section III, NB-3122.3 [15].

Environmental fatigue multipliers were computed for both normal water chemistry (NWC) and hydrogen water chemistry (HWC) conditions in Reference [21] for various regions of the VY RPV and attached piping. Based on VY-specific dates for plant startup and HWC implementation, as well as past and future predicted HWC system availability, it was determined that overall HWC availability is 47% over the sixty year operating period for VY. Therefore, for the purposes of the EAF assessment of the FW nozzle, it was assumed that HWC conditions exist for 47% of the time, and NWC conditions exist for 53% of the time over the 60-year operating life of the plant. RPV upper region chemistry was assumed for the FW nozzle blend radius location, since this location experiences reactor conditions for all times. FW line chemistry was assumed for the FW nozzle safe end location, since this location experiences feedwater conditions for all times.

For the safe end location, the environmental fatigue factors for pre-HWC and post-HWC are both 1.74 from Table 3 of Reference [21] for the RPV FW line. This results in an EAF adjusted CUF as follows:

60-Year CUF, U_{60} = 0.1470 (from Table 4-5)
Overall EAF multiplier, F_{en} = 1.74
60-Year EAF CUF, $U_{60\text{-}env}$ = 0.14709 x 1.74 = 0.2560

The EAF CUF value of 0.2560 for 60 years for the safe end is acceptable (i.e., less than the allowable value of 1.0).

The fatigue calculation documented in Section 4.0 for the blend radius location was performed for the nozzle base material since cladding is structurally neglected in modern-day fatigue analyses, per ASME Code, Section III, NB-3122.3 [15]. This is also consistent with Sections 5.7.1 and 5.7.4 of NUREG/CR-6260 [16]. Therefore, the cladding was neglected and EAF assessment of the nozzle base material was performed for the blend radius location.

For the blend radius location, the environmental fatigue factors for pre-HWC and post-HWC are 11.14 and 8.82, respectively, from Table 4 of Reference [21] for the RPV upper region. This results in an EAF adjusted CUF as follows:

60-Year CUF, U_{60} = 0.0636 (from Table 4-4)
Overall EAF multiplier, F_{en} = (11.14 x 53% + 8.82 x 47%) = 10.05
60-Year EAF CUF, $U_{60\text{-}env}$ = 0.0636 x 10.05 = 0.6392

The EAF CUF value of 0.6392 for 60 years for the blend radius is acceptable (i.e., less than the allowable value of 1.0).

6.0 CONCLUSIONS

This report documents a refined fatigue evaluation for the VY FW nozzle. The intent of this evaluation is to use refined transient definitions and the revised cyclic transient counts for 60 years for a computation of CUF, including EAF effects, that is more refined than previously performed fatigue analyses. The fatigue-limiting locations in the FW nozzle and safe end are included in the evaluation, to be consistent with NUREG/CR-6260 [16] needs for EAF evaluation for license renewal. The final fatigue results are considered to be a replacement to the values previously reported in the VY LRA.

The fatigue calculations for the VY FW nozzle were performed in accordance with ASME Code, Section III, Subsection NB-3200 methodology (1998 Edition, 2000 Addenda) [15]. The stress evaluation is summarized in Section 3.0, and the fatigue analysis is summarized in Section 4.0. The results in Section 4.0 reveal that the CUF for the limiting safe end location is 0.1470, and the CUF for the limiting blend radius location is 0.0636. Both of these values represent 60 years of plant operation, including all relevant EPU effects.

EAF calculations for the VY FW nozzle were also performed, as summarized in Section 5.0. The results in Section 5.0 reveal that the EAF CUF for the limiting safe end location is 0.2560, and the EAF CUF for the limiting blend radius location is 0.6392. Both of these values represent 60 years of plant operation, including all relevant EPU effects.

All fatigue allowables, both with and without EAF effects, are met, thus demonstrating acceptability for 60 years of operation.

7.0 REFERENCES

1. **REDACTED**

2. CB&I RPV Stress Report, Sections T4 and S4, "Feedwater Nozzle, Vermont Yankee Reactor Vessel, CB&I Contract 9-6201," SI File No. VY-05Q-238.

3. GE Design Specification No. 21A1115, Revision 4, "Vermont Yankee Reactor Pressure Vessel," October 21, 1969, SI File No. VY-05Q-210.

4. Kuo, A. Y., Tang, S. S., and Riccardella, P. C., "An On-Line Fatigue Monitoring System for Power Plants, Part I - Direct Calculation of Transient Peak Stress Through Transfer Matrices and Green's Functions," ASME PVP Conference, Chicago, 1986.

5. ANSYS, Release 8.1 (w/Service Pack 1), ANSYS, Inc., June 2004.

6. Structural Integrity Associates Calculation No. VY-10Q-301, Revision 0, "Feedwater Nozzle Finite Element Model and Heat Transfer Coefficients."

7. Structural Integrity Associates Calculation No. YAEC-13Q-303, Revision 0, "Thermal Transient Analysis."

8. VY Drawing No. 5920-9057, Sheet 1, Revision 1, SI File No. VY-05Q-215.

9. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section II, Part D, 1998 Edition, 2000 Addenda.

10. Structural Integrity Associates Calculation No. VY-16Q-301, Revision 0, "Feedwater Stress History Development for Nozzle Green's Function."

11. Vermont Yankee Drawing 5920-00024, Rev. 11, GE Drawing No. 919D294, Revision 11, Sheet No. 7, "Reactor Vessel," SI File No. VY-05Q-241.

12. CB&I Addenda to RPV Stress Report, "Certification of Addenda to the Stress Report for Vermont Yankee Reactor Vessel," July 9, 1971, SI File No. VY-05Q-238.

13. VY Calculation Change Notice (CCN), CCN Number 1 for Calculation VYC1005 Revision 2, "This CCN Provides a Basis for the Power Uprate Safety Analysis Report being submitted as part of the power uprate project. The 50.59 assessment will be handled by the EPU design change and NRC SER for this submittal." SI File Number VY-05Q-208.

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15. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III Subsection NB, 1998 Edition, 2000 Addenda.

16. NUREG/CR-6260 (INEL-95/0045), "Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components," March 1995.

17. GE Certified Design Specification No. 26A6019, Revision 1, "Reactor Vessel – Extended Power Uprate," August 29, 2003, SI File No. VY-05Q-236.

18. General Electric Stress Report No. DC22A5583, Revision 0, Section T, "Thermal Analysis FitzPatrick Feedwater Nozzle Modification," SI File No. NYPA-53Q-212.

19. Entergy Design Input Record (DIR) Revision 1, EC No. 1773, Revision 0 "Environmental Fatigue Analysis for Vermont Yankee Nuclear Power Station," 7/26/2007, SI File No. VY-16Q-209.

20. Chicago Bridge & Iron Company Contractor 9-6201, Revision 2, "Section S4, Stress Analysis Feedwater Nozzle Vermont Yankee Reactor Vessel," SI File No. VY-05Q-238.

21. Structural Integrity Associates Calculation No. VY-16Q-303, Revision 0, "Environmental Fatigue Evaluation of Reactor Recirculation Inlet Nozzle and Vessel Shell Bottom Head."

22. NUREG-1801, Revision 1, "Generic Aging Lessons Learned (GALL) Report," U. S. Nuclear Regulatory Commission, September 2005.

23. Structural Integrity Associates Calculation No. VY-16Q-302, Revision 0, "Fatigue Analysis of Feedwater Nozzle."

24. J. P. Holman, "Heat Transfer," 4th Edition, McGraw-Hill, 1976.

25. J. P. Holman, "Heat Transfer," 5th Edition, McGraw-Hill, 1981.

26. N. P. Cheremisinoff, "Heat Transfer Pocket Handbook," Gulf Publishing Co, 1984.

27. American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Section III, Subsection A, Article 4, 1965 Edition with Winter 1966 Addenda.